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Assessment of Possible Carcinogenic Hazards Created in Surrounding Ecosystems by Oil Shale Developments

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ASSESSMENT OF POSSIBLE CARCINOGENIC HAZARDS CREATED IN SURROUNDING ECOSYSTEMS BY OIL SHALE DEVELOPMENTS

by

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Gerald L. Dassler

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Assessment of the Possible Carcinogenic Hazards
Created in Ecosystems Surrounding Oil
Shale Developments

by

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One of the purposes of an environmental assessment is to foresee potential problems created by the introduction of contaminants into an ecosystem and to suggest appropriate control devices to mitigate the effects of such inputs. In the case of the oil shale industry, very little is known about the potential hazards, especially those related to the emission of organic compounds with carcinogenic potency. The hazards will probably be due to chronic exposures to the emitted compounds and the effects of such exposures are likely to take years to manifest themselves, as is the case with many carcinogenic substances. A precise evaluation of these hazards awaits commencement of operation of commercial scale oil shale processing facilities. However, it is hoped that this report will stimulate future research into the effects and control of discharges of carcinogenic materials from oil shale development sites and possibly other fossil fuel energy development and result in the anticipation of potential problems.

(99 pages)

INTRODUCTION

History and Background

"The time for full-scale commercial development of oil shale in the United States is here." Statements of this nature have been made by government officials and shale industry leaders in the United States for over 100 years. The past two decades have seen an increase in their frequency. However, economic conditions or government policies have never been "just right," and the commercial development of the largest reserve of hydrocarbons in the world has failed to get off the ground.

The term "oil shale" is actually a double misnomer for this hydrocarbon bearing rock. The inorganic matrix is not a shale, but a marlstone. No oil is contained within this marlstone, but rather a solid organic substance known as kerogen. The kerogen, when subjected to heat, breaks down to form shale oil. Some geologists believe kerogen to be incompletely developed oil, having the same biologic origin as natural crudes, but never having been subjected to the heat and pressure necessary for conversion to oil.

The Green River Formation, shown in Figure 1, covers 16,500 square miles of Colorado, Utah and Wyoming and contains the largest oil shale deposit in the world. A more extensive site description is given in the Final Environmental Statement for the Prototype Oil Shale Leasing Program (USDI, 1973). It was here that two prehistoric freshwater lakes–Lake Gosiute in Southern Wyoming, and Lake Uintah in Colorado and Utah–were cut off by the rising of the Rocky Mountains and left to stagnate. As

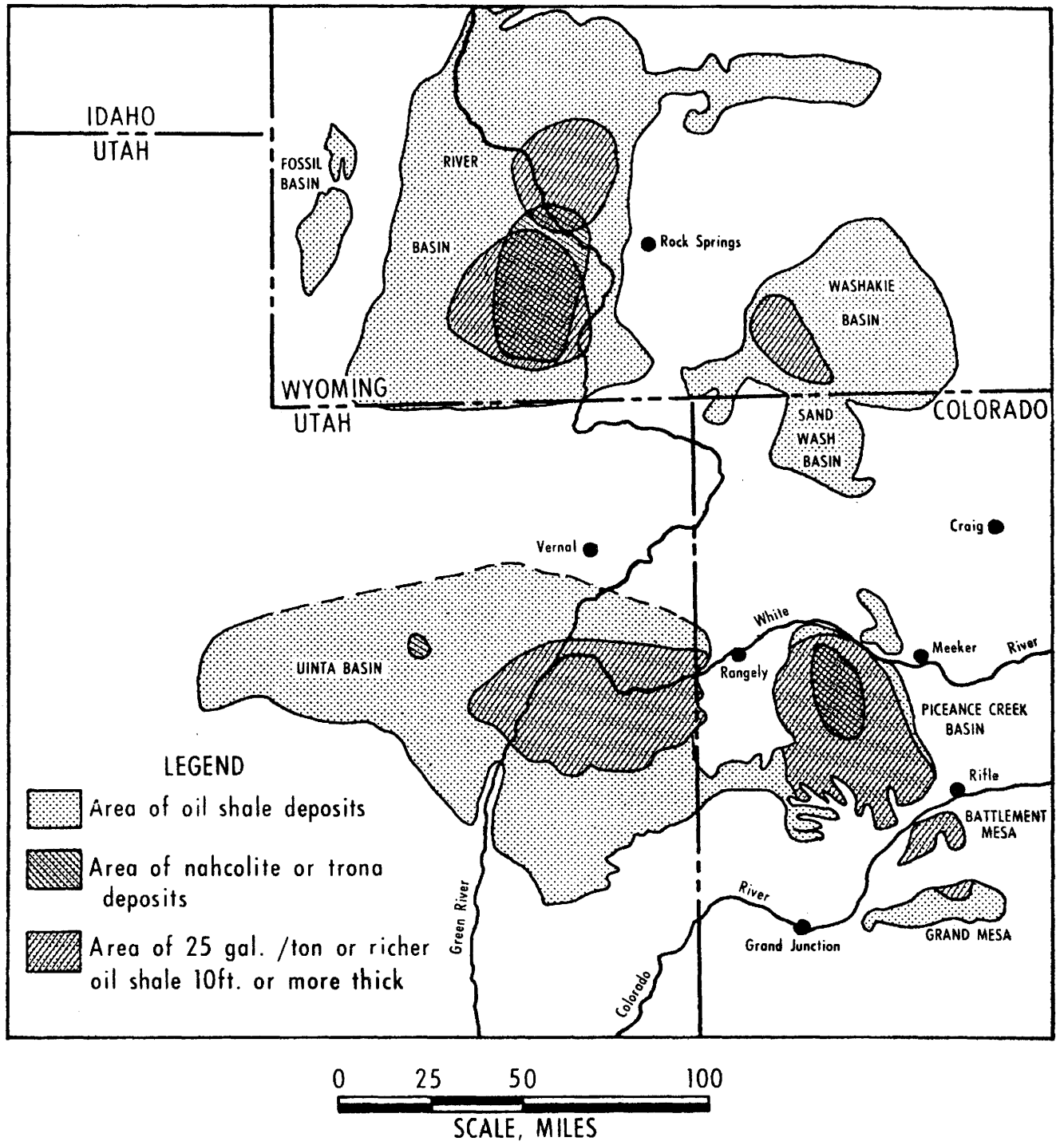

Figure 1. Oil shale deposits in the Green River Formation (taken from USDI, 1973).

the remains of aquatic organisms settled out, they mixed with clay and sand to form sediments at the bottoms of the shrinking lakes. These sediments were then covered by volcanic ash and by rock torn loose from the forming mountains. Eventually the lakes disappeared, leaving pools of crude oil and gas in some areas. However, the continued upward movement of the earth's crust protected most of the deposited organic material from geologic heat and pressure. This protected material took the form of kerogen and became the base of the oil shale deposits we know today.

Oil shale, known by the Ute Indians as "the rock that burns," has long been recognized as a potential reserve of hydrocarbons. It is found in deposits of varying size in many different parts of the world. Its discovery pre-dates the voyage of Columbus to the New World. As far back as 1350, medicinal oils were being produced from shale in Australia. The English government granted a patent to distill "oyle from a kind of stone" in 1694. Oil shale industries existed in Australia, Brazil, Canada, France, and Scotland before 1900. The United States, therefore, is a relative newcomer in developing oil shale.

The history of oil shale development in the United States began with its use as a fuel for heating and cooking by the Indians. Production of lubricants and medicines from Appalachian shale began in the early 1800's. The 1850's saw an oil shale plant actually begin production along the Ohio River, amid talk of an oil shale boom. However this talk was soon replaced by talk of an oil boom with the discovery of Col. E. L. Drake's oil well near Titusville, Pennsylvania. The boom and bust pattern for oil shale development hopes repeated itself throughout the first half

of the 1900's. Each time the prospect of an energy crisis loomed up, oil shale was presented as the promise for the future. Then, just as oil shale would near the brink of commercial development, a new oil field discovery would render it uneconomical. For example, the United States Geological Survey report of 1915 indicated that more than 20 billion barrels of oil were contained in the shales of the Rocky Mountains. National Geographic Magazine, in 1918, expressed the reassurance given to this country by the discovery in this excerpt.

> As the Great Creator, through his servants of old, caused water to flow from the rock in the wilderness, so through twentieth-century science, He is causing oil, for ages locked up in the shales of America, to be released for the relief of human necessity. . . .
>
> No man who owns a motor-car will fail to rejoice that the United States Geological Survey is pointing the way to supplies of gasoline which can meet any demand that even his children's children for generations to come may make of them. The horseless vehicles' threatened dethronement has been definitely averted and the uninviting prospect of a motorless age has ceased to be a ghost stalking the vista of the future. (Mitchell, 1918, p. 196)

Over 30,000 mining claims were subsequently filed on federal lands and nearly 200 oil shale corporations were formed. Some companies actually went into production before the East Texas oil field discovery returned oil shale development plans to their already dusty shelves (Colony and Parahoe, 1974).

Now as the United States faces an energy crisis emanating from its dependence upon foreign oil supplies, oil shale is once more being turned to as the star of hope for the future. The vast quantities of oil locked within the Green River Formation dwarf the known crude oil reserves of the U.S. Once again, oil shale is being envisioned much as it was in 1918.

Many industry leaders and government officials insist that the time for commercial development is upon us. Some, however, feel that ''wolf'' has been cried too often, and that oil shale is no closer to development now, than it was twenty years ago.

Thus, the question of when commercial scale development of this country's oil shale resource will take place remains unanswered. The United States Department of the Interior has predicted a million barrel per day shale oil production by 1985. Some industry leaders assert that this goal cannot be attained because government policies have created adverse conditions for shale development.

Whether or not that goal will be reached by 1985, or indeed, whether the United States will see a commercial oil shale industry during this century are not questions to be debated here. It is logical to assume that, sooner or later, the tremendous hydrocarbon reserve locked in this country's oil shale resource is going to support a commercial industry. This industry may produce fossil fuel energy supplies, or may extract the materials necessary for sustaining the petrochemical industries. Whatever the intent, the oil shale resources of the United States will be tapped in the future. When the commercial development does occur, it is going to have a considerable impact on the environment of the tri-state area of Colorado, Utah and Wyoming.

For the remainder of this report oil shale, raw shale and shale will refer to the oil shale ore as it is taken from the ground; shale oil or raw shale oil will refer to the products of kerogen pyrolysis formed during retorting operations; spent shale or disposed shale refers to the processed oil shale; shale piles refer to accumulations of processed oil shale.

Objectives

The overall objective of this study was to make a theoretical assessment of the human health hazard posed as one facet of the total environmental impact. The facet examined involves the emission of organic compounds having carcinogenic potential from the oil shale processing and disposal sites. The evaluation of the health hazard produced by the carcinogenic potential of these emissions required knowledge obtained from data sources of the identity and quantity of organic compounds which can be emitted, an analysis of the potential for such emissions actually occurring under operating conditions and as assessment of the carcinogenic hazard such an emission could create in the surrounding environment. The scope of this impact was primarily limited to a consideration of Utah oil shale development but the analysis approach could be applied easily to other oil shale areas or to other energy development processes associated with fossil fuels.

Data Sources

Information essential to this study was gathered by reviewing the literature to obtain published data, contacting oil shale development companies, contacting independent research institutions involved in oil shale studies and contacting local, state and federal government agencies concerned with oil shale development.

This literature review was initiated using the Final Environmental Statement for the Prototype Oil Shale Leasing Program. This was followed by reviewing the Oil Shale Symposium Proceedings and then continuing through the various environmental statements prepared by the shale companies and concluding with specific articles and papers dealing with the

carcinogenic aspects of organic compounds present in industrial shale emissions. Published data in the areas of concern for this study was found to be extremely scarce. The reason for this scarcity of information is that most of the related research done up to now on the carcinogenic aspects of oil shale and its products has been performed either by the shale companies or by research institutions under contract to the shale companies. Companies privy to the data gathered from these studies have a distinct economic advantage over competitors due to the expense of such research and the requirements for detailed environmental statements which contain such data. The oil shale companies, therefore, consider these data to be proprietary information (Hendrickson, 1976). Thus it is unavailable to the general public and prevented from public release even if inspected by government agencies (Reynolds, 1976).

Oil shale development companies were initially contacted by letter. The responses were then followed up by phone calls to industry people involved in the area of organic carcinogen studies. Personal visits and interviews were then conducted with some of the industry researchers. However, due to the reasons previously mentioned, the people within the shale industry are very reluctant to disseminate any unpublished information concerning carcinogens and oil shale. Adverse publicity that arose from the Denver Research Institute studies has hardened this position (Coomes, 1976a). Therefore, little additional substantive information was assembled from industry sources.

The work done in the area of oil shale and carcinogenicity by independent research institutions has been centered at the Denver Research Institute. Contacts with researchers there were initially made by letter.

Responses were followed by phone conversations and personal visits and interviews. A substantial portion of the information alluded to, or included, in this report was derived from these contacts.

Governmental agencies on the local, state and federal levels were contacted by letter, phone and personal visits. Officials were helpful but possessed very little information not previously published. This lack of information results from the scarcity of government research in these areas and the previously mentioned prerogative of the shale companies to prevent public dissemination of information by these agencies. Research into the carcinogenic aspects of oil shale is being promoted by agencies such as ERDA. However, the process is very time consuming and study results are years away.

The combination of all these impediments made the assemblage of substantial, reliable data for this study extremely difficult. More than 50 letters were sent to shale industry leaders, government agencies and private research institutions in an attempt to acquire data. The nucleus of the information deficiency lies in the fact that no commercial scale industrial shale processing module has ever come on line in this country. Therefore, there is no real situation from which data can be gathered. The scarce amount of data which is available must be extrapolated by one or two orders of magnitude before it can be applied to a commercial scale industry. It was therefore very difficult to carry out a study of this type and derive explicit results.

Need for the Study

The studies, however, are necessary. While the absence of a commercial module may hinder data gathering, this assessment will permit

industry to implement corrective measures along with development of a resource and process, rather than subsequently. Such coordinated implementation will allow industry to assess the full cost of environmental protection measures prior to development. It will assure that an ongoing multibillion dollar industry will not be threatened with closure because of adverse environmental impacts. This will result in savings of time, money, and energy resources over the long run, as well as insuring the preservation of the surrounding environment.

Method of Analysis

Assessment of the carcinogenic hazard created in the surrounding environment by organic compound emissions from commercial oil shale industrial sites required the formation and implementation of certain assumptions. Use of these assumptions was necessitated by the present lack of substantial published data in these areas.

Evaluation of the carcinogenic hazard was carried out using the organic carcinogen benzo[a]pyrene (BaP) as an indicator compound. The number and diversity of the potential organic compound emissions made the use of an indicator compound essential to the study.

Quantities of BaP emitted for various sources were computed by assuming the development would consist of a TOSCO II retorting facility operating at 100,000 bbl/day. The TOSCO II process was chosen because of its technological advancement and the relatively large amounts of data available on it. A 100,000 bbl/day facility seems to be the economic limit for a commercial module, and will facilitate ''scale up'' or ''scale down'' calculations for different size plants.

GENERAL INFORMATION

The Oil Shale Resource

The United States Geological Survey has estimated that over two trillion barrels of oil is locked within the oil shale deposits which underlie large areas of the United States. None of this oil is deemed to be economically recoverable at the present time. However, the USGS estimates that 418 billion barrels either border on being economically producible or are not producible solely because of legal or political circumstances (Novak, 1976). All of these 418 billion barrels lie within the Green River Formation, which contains about 90 percent of the identified oil shale resources in the United States. Other deposits are, in general, of lower grade and are either too small or too inaccessible to support development.

Oil shale resources are described primarily by their average oil yields as measured by a standardized laboratory technique called the Fischer Assay. High grade shale is normally defined as a deposit which is at least 10 feet thick and yields, on average, 25 or more gallons of oil per ton of shale. Low grade shales contain 10 to 25 gallons of oil per ton and have no thickness restrictions.

The recoverability of an oil shale deposit is dependent not only upon oil yield, but also upon shale zone thickness, overburden thickness, and other minerals present in the shale. The zone and overburden thicknesses are interrelated factors influencing the economics of recovery. The existence of marketable minerals, such as nacholite, trona, and dawsonite, may enhance economic recovery of oil shale.

The private ownership of mineral rights to oil shale resources within the Green River Formation has become very diversified over the years. There are 85 separate private ownerships within the Uintah Basin alone (Cameron, 1974). Maps showing the extent of private ownership within both the Uintah Basin of Utah and the Piceance Creek Basin of Colorado are available from Cameron Engineers Inc. through the Western Oil Reporter.

Retorting Technologies

It has long been known that petroleum liquids and gases can be obtained by heating oil shale in an oxygen limited atmosphere. Temperatures of 800-1000^{o}F will pyrolyze the shale kerogen, resulting in the formation of raw shale oil and various hydrocarbon gases. There are two basic techniques for recovering oil and gas from oil shale. The first involves underground mining of the shale combined with surface retorting. The second technique is termed in situ processing. Figure 2 shows the relative state of technology for the various phases of each method.

Surface retorting involves pyrolyzing the kerogen in a closed vessel called a retort. Heat for pyrolysis is supplied either from sources external to the retort or by internal combustion of a portion of the produced hydrocarbons. In situ processing recovers oil and gas from the shale with the shale remaining in place underground.

At the present time, surface retorting represents the most technologically advanced form of recovery. However, research on the in situ technique is continuing, and this process may be the key to extensive future development of oil shale in the United States.

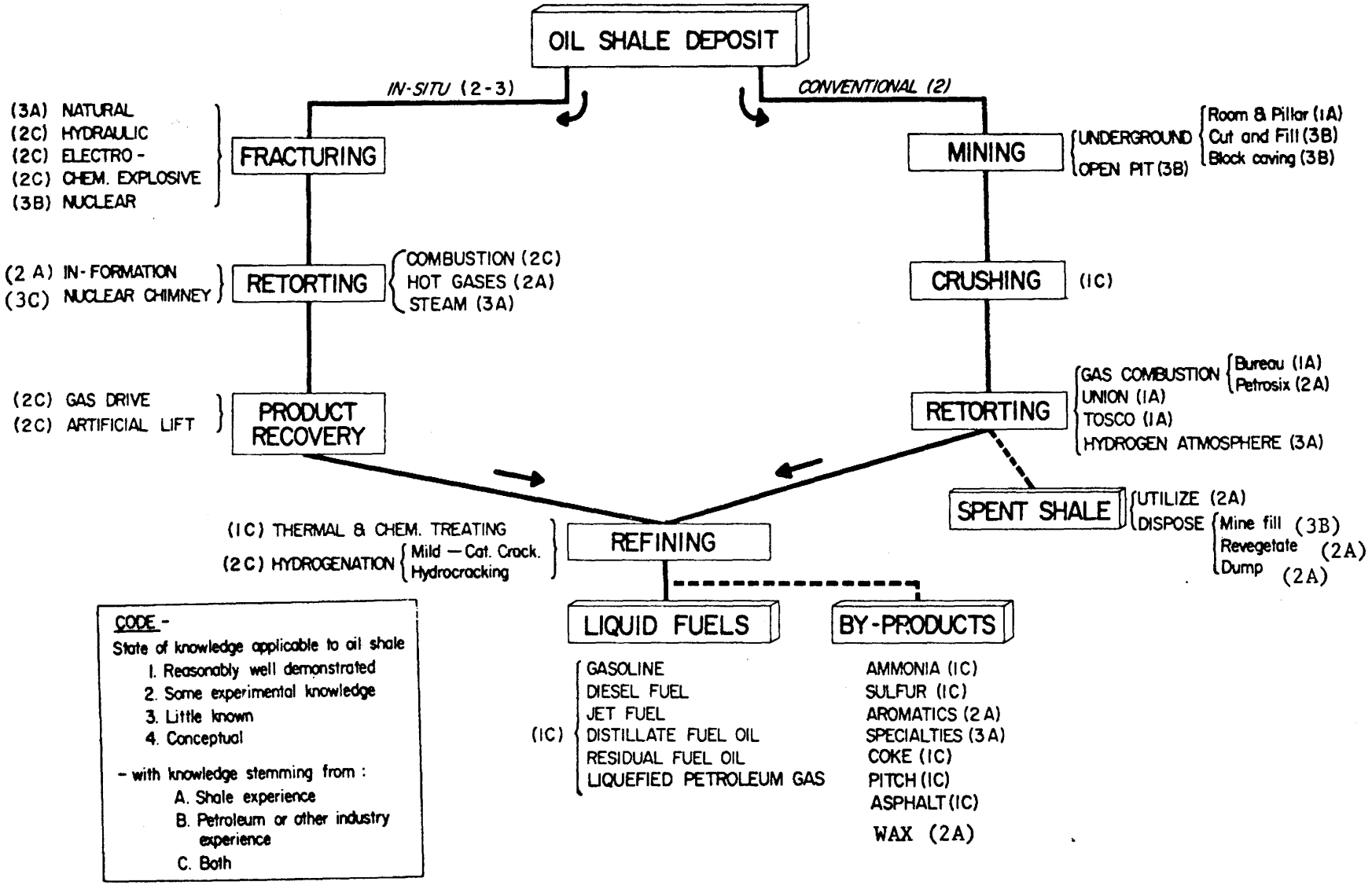

Figure 2. Relative state of knowledge of various operations required in oil shale processing (taken from USDI, 1973).

Currently, four models of the surface retort have advanced to the stage of possible commercial application in the United States. They are the TOSCO II, Union Oil, Paraho and Superior retorting processes. These models differ according to the method used to introduce heat into the retort, retort configuration, shale sizes acceptable, and pattern of shale and gas flow within the retort. All surface retorts produce not only shale oil and gases but also spent shale and water vapor. The spent shale and produced water are essentially waste materials and serve as basic mechanisms for transporting organic compounds from the retorting facility into the surrounding environment.

The central feature of the TOSCO II retort, shown in Figure 3, is a horizontal rotary kiln in which pyrolysis is accomplished by mixing externally heated ceramic balls with preheated shale crushed to minus one half inch. The shale is brought to a retorting temperature of $900^{o}F$ through conductive and radiant heat exchange with the ceramic balls. The oil, steam and gases are given off as a mist which is then collected for recovery of the petroleum products. The spent shale, along with the ceramic balls, is discharged from the kiln and sent to a trommel screen separator. The ceramic balls are then recirculated through the ball heater, while the spent shale is removed for disposal. TOSCO II retorts are able to utilize all of the shale which is mined, have good heat transfers, high shale throughput rates, and give excellent oil recoveries. It is anticipated that the TOSCO II process will be employed by the Rio Blanco Oil Shale Project on federal lease tract C-a, the Colony development operation on tract C-b, and by The Oil Shale Corporation

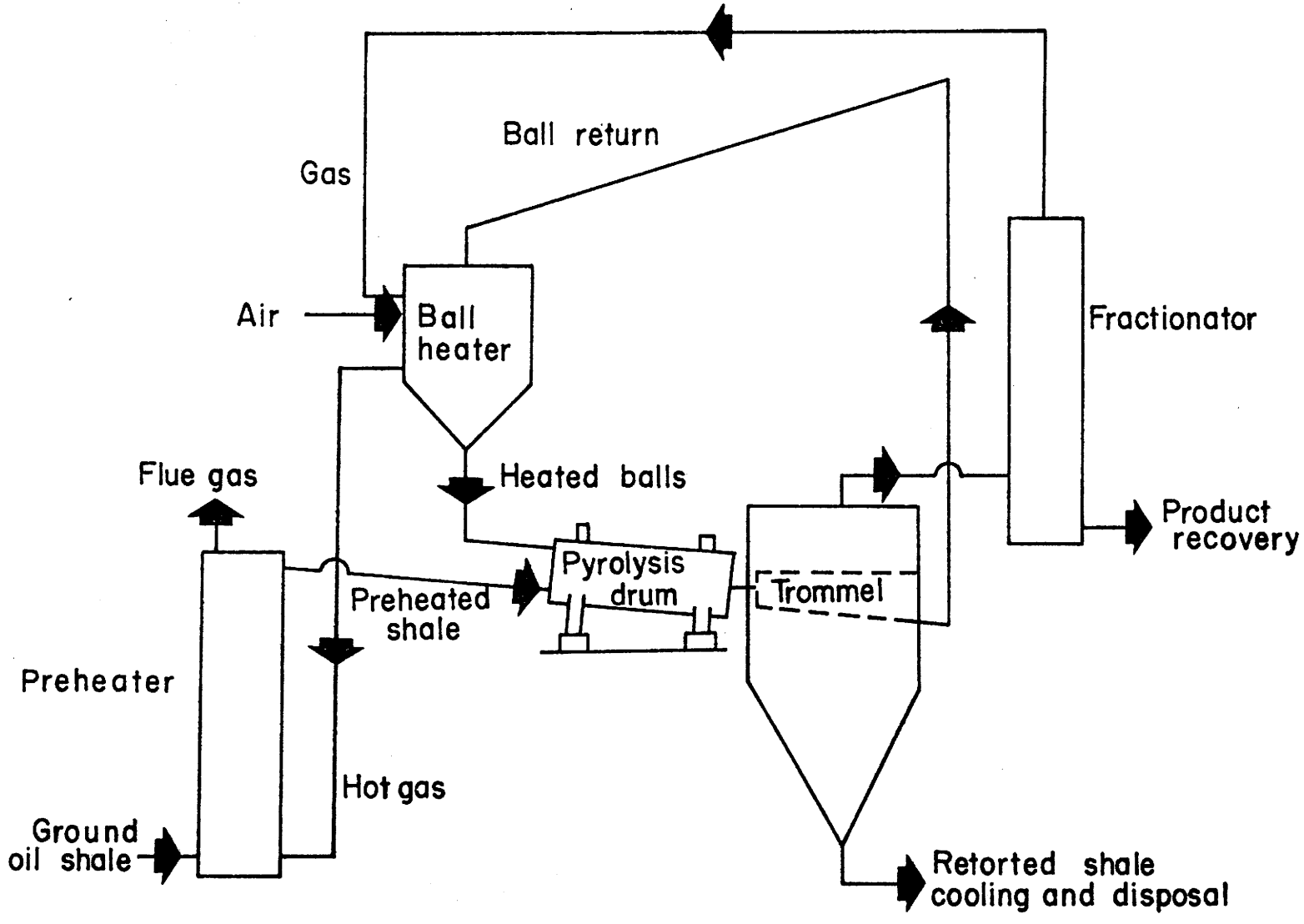

Figure 3. The TOSCO II Process (taken from University of Oklahoma, 1975).

on its private lands in Utah (Novak, 1975). TOSCO II retorts may also be used in combination with other retort processes which are unable to handle fine shale particles.

The Union Oil Company process employs a countercurrent flow of oil shale and air in a vertical, refractory lined vessel. A diagram of the retort is shown in Figure 4. It operates on a downdraft principle, with the shale moved upward by a unique charging mechanism referred to as a rock pump. Heat for pyrolysis is supplied by internal combustion of the carbonaceous residue remaining on the retorted shale. Shale feed rates are adjusted to maintain the combustion zone a short distance below the surface of the bed. Some of the product oil is condensed on the cool incoming shale while the remainder is drawn off as a mist with the product gases and steam. Spent shale leaves the top of the retort in the form of clinkers, with very little residual carbonaceous material remaining. The Union Oil retort employs lump shale with a 3 inch maximum size from which all fine particles have been removed. It requires no cooling water. Union plans to use the process on its shale holdings on Parachute Creek in Colorado (Novak, 1975).

The Paraho process is a modification of the conventional gas combustion retort shown in Figure 5. The retort consists of a vertical, refractory lined vessel through which shale flows downward by gravity countercurrent to the retorting gases. Shale feed rates are controlled by a grate at the bottom of the retort. Recycled product gases enter the bottom of the vessel and cool the exiting shale as they pass upward. The process can be operated in either a direct or an indirect mode.

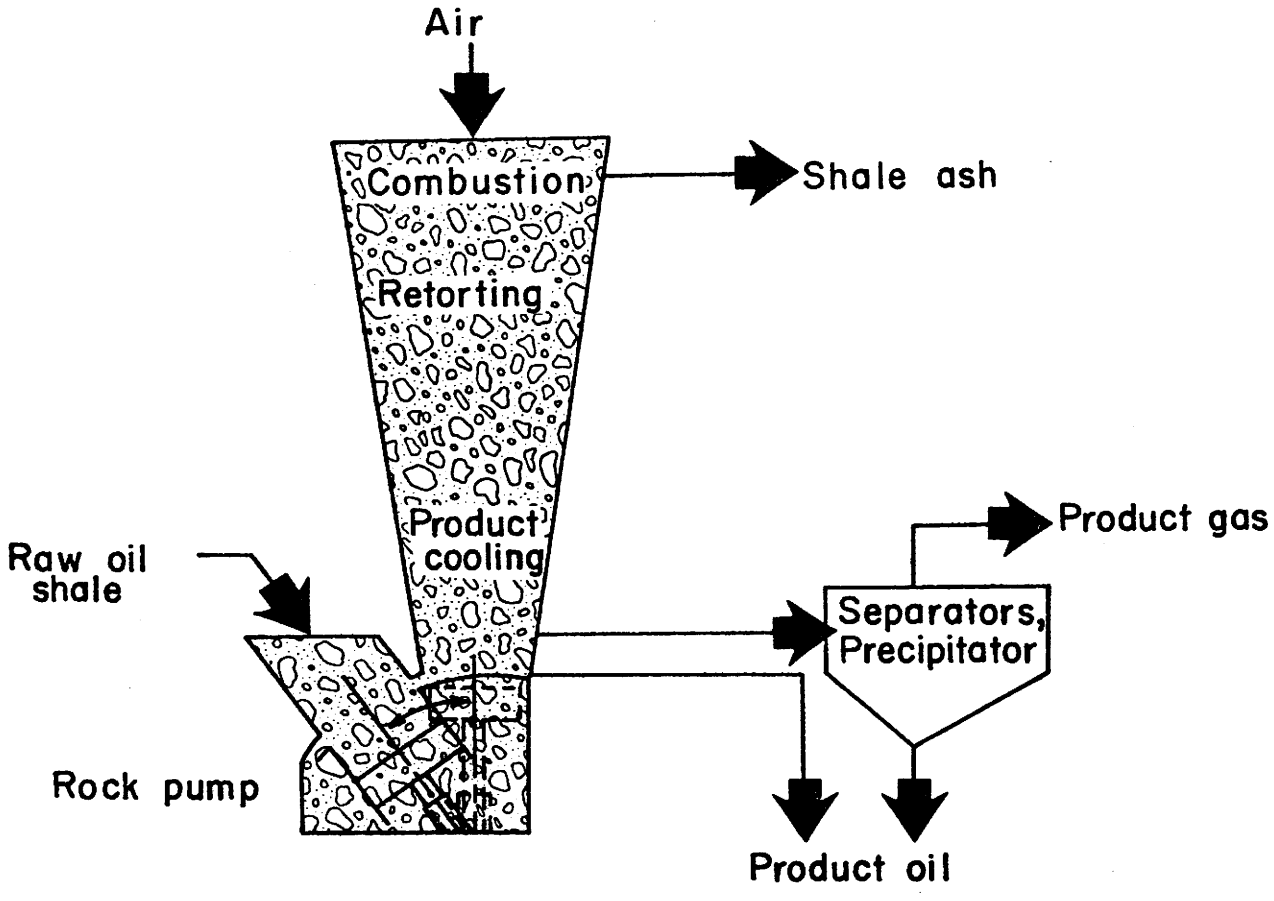

Figure 4. The Union Oil Process (taken from University of Oklahoma, 1975).

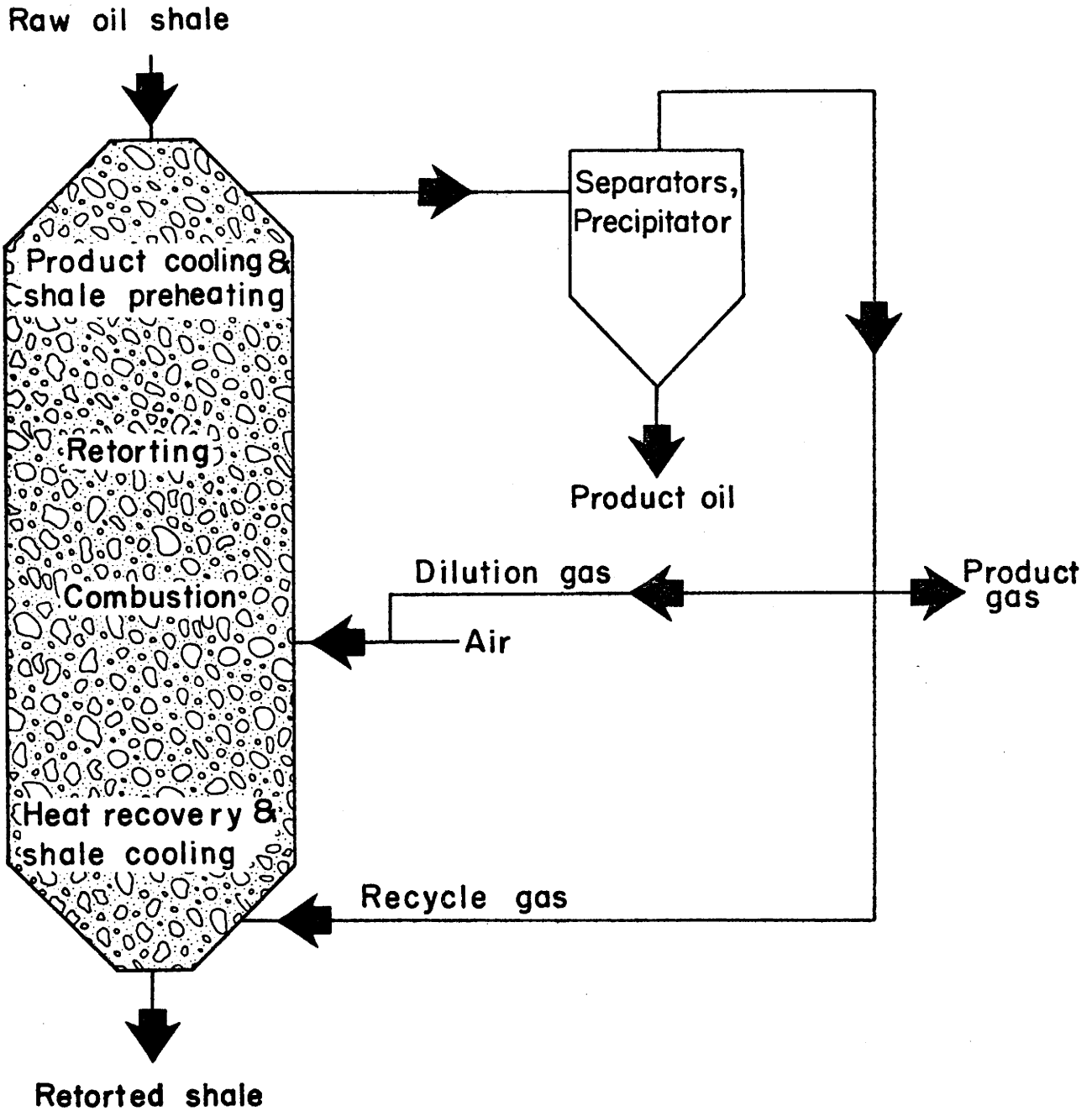

Figure 5. The conventional gas combustion process (taken from University of Oklahoma, 1975).

During direct mode operation recycled gases enter the bottom of the retort and are heated by the hot, retorted shale as they flow upward through the vessel. Air and some additional recycle gases are injected into the retort through a vertically spaced distributor system. These injected gases are intermixed with the rising, hot recycled gases. Internal combustion of these gases and of some residual carbonaceous material attached to the shale provides the heat necessary for pyrolysis. A proper temperature profile is maintained by controlling the flow of air into the retort.

The indirect mode of operation eliminates combustion within the retort vessel. Process heat is supplied by cycling product gases through external heaters. The heated gases are then injected into the retort through distributors at two levels. The injected gases, when combined with the ascending, preheated gases introduced at the bottom of the vessel, provide the heat required to retort the shale.

An oil mist is formed near the top of the shale bed during operation in both direct and indirect modes. This mist is drawn off with the product gases and recovered. Product gases from the indirect mode have a higher BTU content than those from the direct mode, since none of the indirect mode gases have been combusted. The Paraho process gives high retorting and thermal efficiencies and does not require cooling water. It will probably be employed by the various participants in the Paraho Oil Shale Demonstration on their private shale lands which are distributed throughout the Green River Formation. The White River Shale Project, operating on federal lease tracts U-a and U-b, in Utah may also use the Paraho process.

The Superior retorting process is a recent addition to surface retorting technologies. It is an integrated process which extracts not only petroleum products from the oil shale but also nacholite, alumina and soda ash. The process employs a traveling, circular grate retort which resembles a large doughnut. A process diagram is shown in Figure 6. Detailed information as to the mechanics of the process is considered proprietary and therefore not available. The process is reported to be very heat efficient. It requires no cooling water and produces relatively small quantities of spent shale due to the mineral extractions. Superior has plans to use the process on lands it holds in the Parachute Creek area of Colorado.

There are, of course, other surface retorting technologies in existence that have been, or could be, adapted to processing American oil shales. The future may see use of one or more of these processes, or a currently undiscovered technology.

However, the technologies presented here seem to hold the most promise for development of oil shale resources in the foreseeable future.

In situ, or in place, processing of oil shale is still felt to be in the experimental stages of development. However, its technologies are being advanced by companies such as Occidental Petroleum Corporation (OXY) and the Western Oil Shale Corporation (WESTCO).

This method of retorting involves fracturing the shale bed either hydraulically or with explosives in order to create a permeated mass. Heat required for retorting is then supplied by means such as combustion of hydrocarbons within the geological formation, injection of hot gases

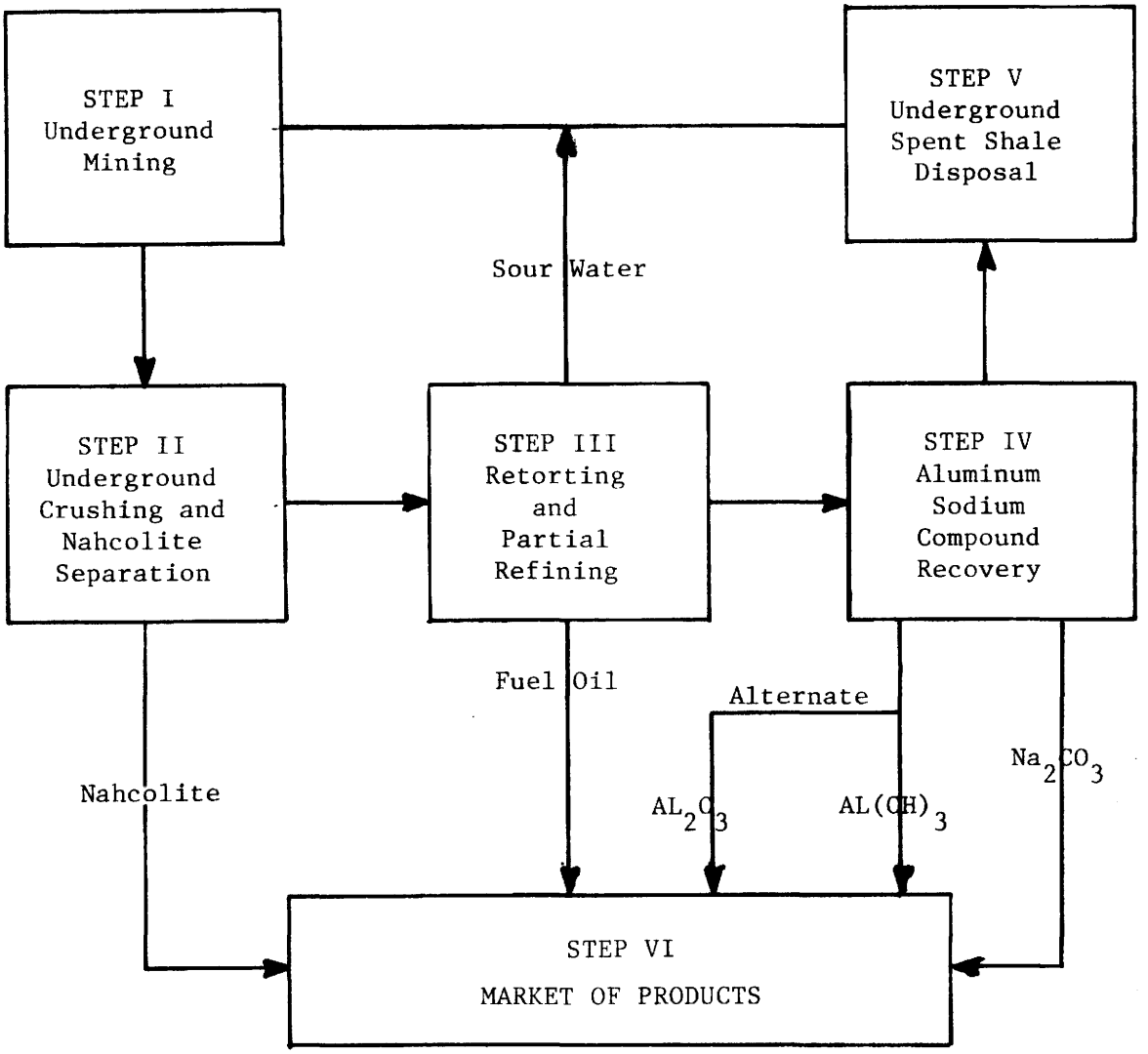

Figure 6. The Superior Process (taken from Anonymous, 1975).

or the introduction of hot liquids. The retorted oil is then collected in wells or sumps and is pumped to the surface. The in situ method of extracting oil from shale has generated much research interest because of the potential advantages it offers over underground mining and surface retorting schemes. It is estimated that in situ production would require 1/3 of the operating personnel, 1/2 to 1/3 of the water and less than 1/3 of the spent shale disposal area necessary for a conventional

surface retorting facility (USDI, 1974). Scarring of the environment by mining and retorting facilities would be minimized. It would allow for more extensive resource recovery since lower grade shales could be processed. However, problems have arisen in creating sufficient permeability within the formation to allow for the passage of gases and liquids. The process is also very difficult to control effectively.

In situ retorting can be accomplished in either a conventional, horizontal pattern, as shown in Figure 7, or in a modified, vertical scheme which is essentially the horizontal process rotated 90^{o}. The modified method is being promoted by both OXY and WESTCO, therefore it alone will be discussed here.

Modified in situ retorting schemes do involve some underground mining. First, a cavity is created by removing a quantity of shale deep in the formation. The shale above the cavity is then fractured by explosives which causes the rubble to fall into the cavity, thus forming a permeated chimney of shale, equivalent to a vertical underground retort. Heat is then applied to the top of the chimney by one of the aforementioned methods. The fire or hot liquids or gases sweep down through the rubble, driving retorted oil ahead. The oil is then collected in a previously constructed sump at the bottom of the chimney and pumped to the surface.

OXY has conducted several pilot scale studies at a site in Logan Wash, Colorado. These studies have been reported as successful, although detailed information is considered to be proprietary (McCarthy, 1976). Commercial development at the Logan Wash site is anticipated. WESTCO

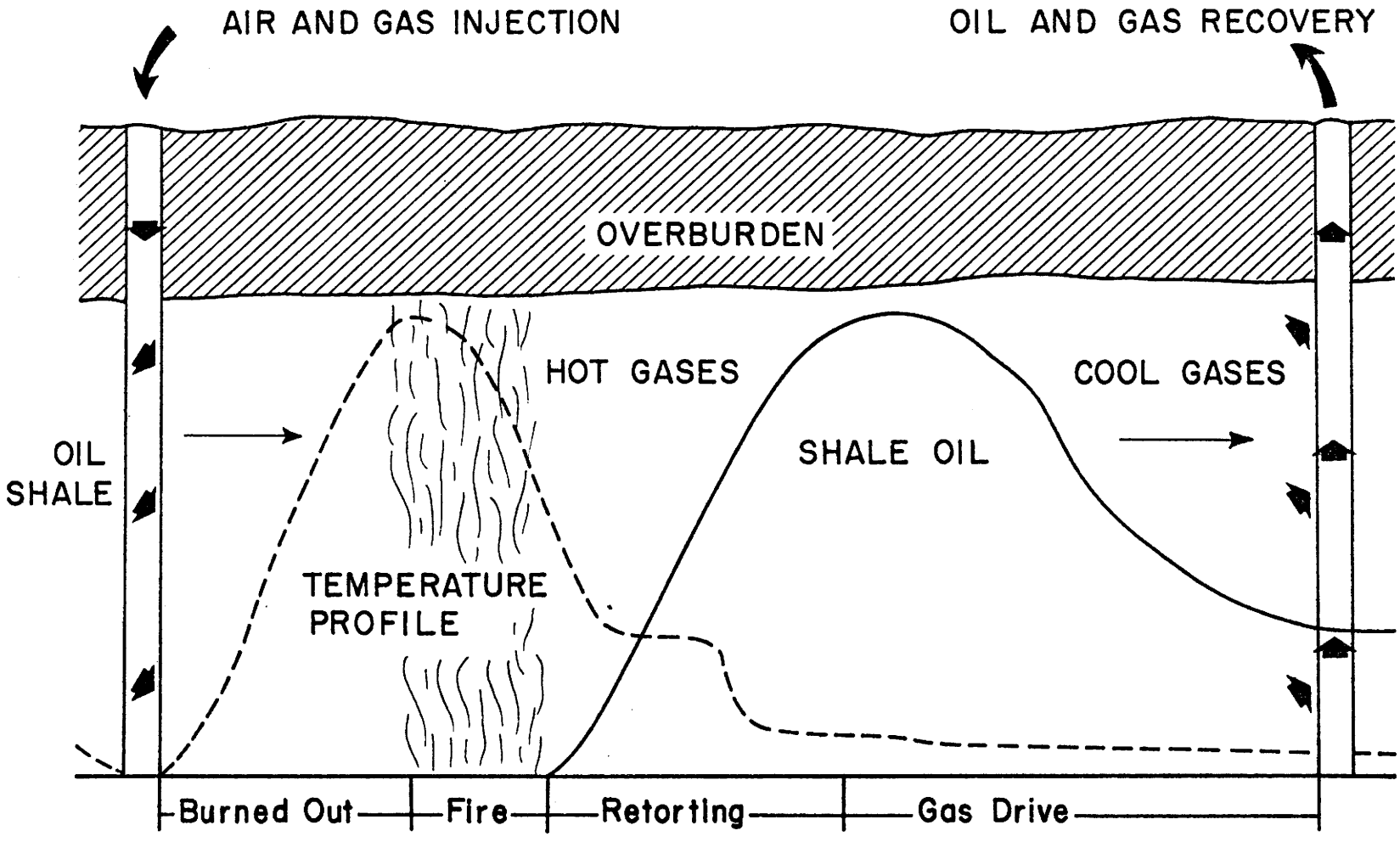

Figure 7. The in situ retorting process (taken from USDI, 1973).

holds a large amount of shale land in Utah and is currently carrying out studies in that state.

State of the Industry

Developers of the TOSCO II, Union Oil and Paraho retort processes have declared that their technologies are ready to be developed on a commercial scale whenever economic conditions warrant (Novak, 1975). Superior states that its process is economically feasible for commercial production now and that only a favorable governmental decision on a land swap proposal is required to initiate development (Weichman, 1976). OXY has predicted that their modified in situ research efforts will result in the first commercial size oil shale retorting operation in the United States (Novak, 1975). Despite all of these contentions, no one in the shale industry seems willing to make a definite statement concerning the schedule for, or scale of, future commercial oil shale development. Thus, the prediction of the future development of oil shale in the United States becomes very difficult.

It is reasonable to assume, however, that the oil shale industry will mature much as other mineral industries have done. The initial developments in the immature industry will involve a flourish of retorting technologies, both surface and in situ. The process of maturation will eliminate all but the most reliable and efficient schemes. The matured industry will consist of one or two retorting techniques which will be responsible for processing the vast majority of shale over the long run.

Assumptions about Oil Shale Technology Application

This study will confine itself to looking at organic emissions from first generation, surface processing, shale technologies. Even this restriction, however, does not bring the carcinogenic potential of these emissions down to a scope which can be dealt with here. Therefore, it will be necessary to choose a specific technology and development scale and conduct the investigation from that assumed viewpoint. This will allow for a tentative identification and quantification of organic compound emissions, an analysis of the potential for such emissions actually occurring, and an evaluation of their effect on the environment.

Therefore, it was assumed that the oil shale development would incorporate a TOSCO II retorting facility capable of producing 100,000 barrels of raw shale oil per day. The TOSCO II technology was selected because of the relative abundance of data available on the process itself and its emissions. Limited information concerning the carcinogenicity of TOSCO II retort products is available in the published literature. Extensive environmental studies have been conducted based on a TOSCO II retort facility. The process also possesses the ability to handle fine shales at high efficiencies which makes it a prime contender for a position in continuing technology. The 100,000 bbl/day facility was selected because it appears to be the limiting size for a commercial production module. A facility of this size would cost around one billion dollars (Anonymous, 1976), which would be a significant investment by any company on a risky, first generation development.

CARCINOGENIC POTENTIAL OF OIL SHALE AND SHALE PRODUCTS

Background

The processing of oil shale essentially involves the conversion of raw shale to spent shale and shale oil. Therefore, all organic compounds produced in shale processing must reside in one of these three materials. Air or water which comes in contact with the raw shale, spent shale, or shale oil can be expected to become contaminated by the organic compounds contained within or on the respective material. An assessment of the carcinogenic potential of the raw oil shale, the spent shale and the shale oil will then provide an insight into the carcinogenic nature of the air and water emissions from the retorting and disposal sites. This indirect approach to the assessment is made mandatory by the almost total absence of data regarding the organic compounds contained in these emissions.

The carcinogenic potency of materials can be evaluated in three basic ways. The first consists of chemical analysis for substances which are known to be carcinogenic. Usually a specific indicator compound, such as benzo[a]pyrene (BaP), is selected for analysis.

The second method is based on a mutagenic screening of suspected carcinogenic materials. Pure strains of bacteria are exposed to concentrations of test substances and mutations are observed (McCann and Ames, 1976).

The third method involves subjecting test animals to the suspected materials for extended periods of time and observing their reactions. This procedure is known as bioassay testing.

Chemical analysis for the presence of indicator compounds and mutagenicity testing can only be regarded as screening procedures. Many substances which contain substantial concentrations of the indicator BaP have shown a lack of carcinogenic activity. Oak leaves are an example of such a substance (Atwood and Coomes, 1974). Mutagenic properties of a material do not necessarily infer that the material has carcinogenic properties (Rubin, 1976). Both techniques do, however, provide excellent "red flag" results. Positive indications of carcinogenicity resulting from these tests suggest that further study is necessary. The further study usually takes the form of a biotest assay, which is too complex and expensive to run on thousands of suspected materials, but can provide the most reliable information concerning carcinogenic potency (Atwood and Coomes, 1974).

Description of Oil Shale

Raw oil shale is composed of an inorganic matrix containing solid organic material. The soluble portion of the entrapped organic substance is known as bitumen and comprises about 20 percent of the total. The remaining insoluble portion is referred to as kerogen. Investigations into the hydrocarbon structure of kerogen from American oil shales have been conducted by Schmidt-Collerus and Prien (1976) and by Yen (1976). Yen (1976) concluded that aromatic hydrocarbons were virtually non-existent in the kerogen. This is an important note, since the

carcinogenicity of petroleum products has usually been linked to the presence of polycyclic aromatic hydrocarbons (PAH) (Schmidt-Collerus et al., 1976). Thus, the absence of PAH in kerogen would indicate low or non-existent carcinogenicity. Yen (1976) also points out that the structure of the kerogen is a multipolymer consisting of monomers which are the molecules so far identified from bitumen origin. Therefore, the bitumen constituents are, in all probability, also non-aromatic. The seemingly low carcinogenic potential of raw oil shale has been borne out in bioassay tests carried out by a private research institution under contract to TOSCO. Coomes (1976b) reported preliminary results of these tests at the Ninth Oil Shale Symposium. Mice exposed to raw oil shale for extended periods of time developed no skin cancers. The raw shale even became intermixed with their food and water. However, no digestive tract cancers were reported in any of the mice examined. Studies by Berenblum and Schoental (1943) indicate that BaP is not present in raw shale. The raw shale, therefore, can be treated as a carcinogenically inactive material and will not be dealt with in the remainder of this report.

Shale Oil

Pyrolysis of the kerogen to produce shale oils results in the formation of polycyclic organic matter (POM) which contains PAH in addition to other types of high molecular weight organic compounds (Schmidt-Collerus et al., 1976). These compounds are, of course, present in the shale oils and can be expected to be contained in any carbonaceous coating which forms on the spent shale. It is also plausible to expect that the retorted hydrocarbon gases will include these materials.

The carcinogenic nature of shale oils has been recognized for many years. Skin cancers appearing on workers in the Scottish shale oil industry were observed and reported by Scott (1922). Subsequent studies by Leitch (1922), Kennaway (1924) and Hueper (1953) confirmed the carcinogenic properties of shale oils. Therefore, emissions which have come in contact with the raw shale oil can be expected to bear carcinogenic potentials.

Spent Shale

Spent shale from the TOSCO II retort is a fine material containing 3 to 5 percent organic carbon (Schmidt-Collerus, 1974). This carbon residual results from the relatively low pyrolysis temperatures and the absence of internal combustion in the TOSCO II process. The residual is the source of organic carcinogens in the spent shale. Different retorting techniques will, of course, leave different carbon residuals and therefore different amounts of organic carcinogens on the spent shale. Schmidt-Collerus (1974) found that the carbonaceous residue on TOSCO II spent shale contained polycyclic organic matter (POM) including PAH and aza-azarines (AA) in addition to other higher molecular weight organic compounds. This compares closely with his analysis of shale oil. Table 1 lists the POM he identified in spent shale extracts along with a relative rating of their potential carcinogenicity. Concentrations of these compounds have not been reported to date.

The carcinogenic potential of spent shale was also evaluated in the mouse studies carried out for TOSCO. The preliminary results, as reported by Coomes (1976b), indicate that neither skin nor digestive tract

Table 1. POM compounds identified in benzene extract of carbonaceous shale coke from Green River Oil Shale (taken from Schmidt-Collerus, 1974).

Name of Compound	Potential Carcinogenicity[a]
phenanthrene	--
fluoranthene	--
pyrene	--
anth anthrene (dibenzo[cdjk] pyrene	--
benz[a] anthracene (1,2-Benzanthracene)	+
benzo[a] pyrene	+++
7,12 - dimethyl[a] anthracene	++++
perylene	--
acridine	--
dibenz[a,j] acridine (1,2,-7,8-dibenzacridine)	++
phenanthridine	?
carbazole	--

[a]The greater the number of (+) signs, the greater is the potential carcinogenicity of a particular compound.

cancers were induced by contact with the spent shale. This would seem to infer that the spent shale has a low carcinogenicity, much like that of the raw shale. However, the identification of known organic carcinogens in the spent shale indicates that much more extensive investigation is required. Actual leachates need to be examined since the carcinogens present in the spent shale may be tied up in an inorganic matrix and therefore are not available for interaction (Coomes, 1976a).

Indicator Compound

The carcinogenic potential of air and water emissions from oil shale retorting and disposal sites has not been extensively investigated. No bioassay tests have been conducted on pilot plant or semi-works scale emissions to date. The use of mutagenic screenings is a relatively new

technique and it has not yet been applied to shale site emissions. Therefore, the only avenue left open for assessing the carcinogenic potential of these emissions is examination for the presence of an indicator compound. The presence of BaP will be assumed to be indicative of carcinogenic potential.

BaP was chosen as the indicator compound because it has historically been employed in this capacity. It has been called the most important carcinogen because its fluorescence spectrum is highly characteristic and is so intense that it is able to overcome the combined fluorescence of the hundreds of hydrocarbons which accompany it in cancer producing substances. This phenomenon led to the discovery of the carcinogenic hydrocarbons (Heiger, 1961). Over the years British and American scientists have investigated hundreds of chemicals and found many of them to be carcinogencially active, however only about half a dozen have found regular use in cancer research. These compounds are known to induce tumors under appropriate conditions in many animal tissues, whereas the vast majority of the other compounds have been inadequately tested. One of the foremost compounds in this group is BaP (Clayson, 1962). BaP was the first carcinogen to be discovered in Scottish shale oil. It is formed during the pyrolysis of carbonaceous materials (Heiger, 1961). Thus its ease of identification, known carcinogenicity and origin made it a most likely candidate for an indicator compound. The presence of BaP in air or water emissions from the shale retorting and disposal sites would therefore indicate the contamination of these emissions by aromatic hydrocarbons, and would point to a potential carcinogenic hazard.

Recently, mutagenic screening tests have been conducted on a number of compounds suspected of being carcinogens (McCann et al., 1975). The test results showed a 90 percent correlation between carcinogenicity and mutagenicity among the 300 compounds examined. Table 2 shows the mutagenic potency of polycyclic aromatic hydrocarbons which have been identified in oil shale processing products. The number of revertants per nmole is an indication of the mutagenic potency of the compound. Thus, it can be seen that of the compounds identified in shale products and tested, BaP is by far the most potent mutagen. Within the 90 percent correlation limits it can probably be assumed that BaP is also one of the most potent carcinogens present in the oil shale products. In fact, if the mutagenic potency is directly related to carcinogenic potency, BaP becomes a more potent carcinogen than all of the other compounds combined.

Therefore, the presence of BaP serves not only as an indicator of carcinogenic potential, but also as a measuring stick for carcinogenic potency. The BaP content of selected materials is given in Table 3.

Table 2. Mutagenic potential of selected PAH found in spent oil shale from TOSCO II process (taken from McCann et al., 1975; and Schmidt-Collerus et al., 1976).

Compound	Revertants per nmole
Anthracene	<0.01
Benz[a]anthracene	11
Benzo[a]pyrene	121
Chrysene	38
Dibenz[a,j]acridine	18
7,12 Dimethylbenz[a]anthracene	19
Phenanthrene	<0.25
Pyrene	<0.02

Table 3. Contents of benzo[a]pyrene (BaP) in natural and industrial materials (taken from Atwood and Coomes, 1974).

Substrate Material	Benzo[a] pyrene (parts per billion)
Natural Materials	
Coconut oil	43.7
Peanut oil	1.9
Oysters (Norfolk, Va.)	10 to 20 (based on dry weight)
Forest soil	4 to 8
Farm field near Moscow	79
Oak leaves	300 max
Petroleums and Petroleum Products	
Libyan crude oil	1,320
Cracked residuum (API Smpl 59)	50,000
Cracked sidestream (API Smpl 2)	2,000
West Texas paraffin distillate	3,000
Asphalt	1×10^4 to 1×10^5
Oil Shale Related Materials	
Carbonaceous spent shale (Colony), CSA II (2)	46
Carbonaceous spent shale (Colony)	13
Carbonaceous spent shale (USBM, Anvil Points) CSA III	15
Processed Shale (Colony)	100
Raw Shale Oil (Colorado)	30,000-40,000
Hydrotreated Shale Oil (0.25%N)	6,900
TOSCO II Shale Oil, unrefined	4,000
TOSCO II Shale Oil, refined (0.05%N)	800
TOSCO II Processed Shale	40
Coals	
High volatile	4,200
Low volatile	3,150
Pocahontas	1,200
Coal tar	3×10^6 to 8×10^6

It should be noted, that chemical analysis for BaP does have its weaknesses when used as an indicator of carcinogenicity. Atwood and Coomes (1974) point out that the presence of BaP does not positively relate to the carcinogenicity of many materials. Hueper and Cahnman (1958) have shown that fractions of American shale oils free of BaP still possess appreciable carcinogenic properties. However these failings are essentially overcome when BaP is used as an indicator of the carcinogenic

potential of shale site emissions. Shale oil has been proven carcinogenic to man and animals (Scott, 1922; Leitch, 1922; Kennaway, 1924; and Hueper, 1953) and is known to contain BaP. Thus the presence of BaP in shale site emissions would, in all probability, indicate a carcinogenic potential. Since the emissions will contact whole shale oil and not fractionated products, it can be reasonably assumed that the absence of BaP will indicate a lack of contamination by shale hydrocarbons. Viewed in this light, BaP becomes an excellent indicator of the carcinogenic potential of shale processing and disposal site emissions.

Animal uptake and retention studies have been carried out to some extent with BaP. Rigdon and Neal (1963) found that when dogs, mice, chickens and ducks were fed BaP, blue fluoresence of the skin and viscera developed. The fluoresence disappeared when feeding stopped. Rigdon and Rennels (1964) noted that rats fed BaP developed a blue fluoresence in their viscera. They also found that fetuses, as well as the uterine wall, fetal membrane and placenta, taken from mother rats fed BaP had the blue fluoresence.

Howard and Teague (1965) noted that BaP is soluble in milk and Rigdon and Neal (1963) confirmed that the agent responsible for the blue fluoresence was transmitted through the mother's milk to young mice.

Huggins and Yang (1963) discovered that BaP, when fed to rats along with their diet, caused breast cancer in 89 percent of the studied animals.

Therefore, BaP is not only an indicator and measuring stick of carcinogenicity, but is also a compound which can be taken up and retained and transferred by birds and mammals.

POTENTIAL CARCINOGEN RELEASE PATHWAYS

General

The carcinogen emissions from oil shale retorting and disposal sites will be evaluated on the assumption that they are related to the BaP content of the emission. The transportation of organic carcinogens from the shale sites into the surrounding environment can be accomplished through the gas emissions, water emissions, or with the shale oil itself. Therefore, an assessment of the sources of BaP related to each transport medium, the respective quantities of BaP available for release and the potential for such releases actually occurring under operating conditions will be made.

Atmospheric Emissions

Quantities of potentially carcinogenic organic material may be carried from the shale retorting and disposal sites directly to the atmosphere by retort off gases containing hydrocarbons and spent shale dust, with spent shale dust generated during disposal operations and by fumes and vapors created by the volatilization of organics in the spent shale piles. For the purpose of this study, the spent shale dust contained in the retort off gases and that arising from the disposal operations will be considered as a single source of organic compounds.

Hydrocarbon emissions predicted by the Colony Development Operation for a 50,000 bbl/day shale oil plant employing TOSCO II retorting facilities are shown in Table 4. The figures of interest for the retorting

Table 4. Average expected hydrocarbon emissions for the proposed Colony Shale Oil Plant (taken from USDI, 1975).

Sources located at plant site	No. of Stacks	Total TH emission rates for all stacks kg/hr
Preheat systems	6	122.7 136.3
Elutriator systems	6	0.13 0.13
Coker heater	1	0.09 0.09
Gas-oil reactor feed heater	2	0.04 0.04
Gas-oil reboiler furnace	1	0.09 0.09
Naphtha reactor feed heater	1	0.46 0.46
Hydrogen reforming furnace	4	0.72 0.82
Boilers (auxiliary)	2	0.18 0.23
Sulfur plant tail gas unit	1	0.00
Shale wetter	6	0.00
Fine ore storage	1	0.00
Fine ore crusher	4	0.00
Mine ventilator	3	22.70
Total for Plant Site	38	147.1 138.1
Sources Located at Grand Valley		
Utility boilers	2	0.00
Total for Both Sites	40	147.1 138.1

Note: Emission rates on first line are normal, rates on second line are peak values.

operations include those from the preheat and elutriator systems. These two sources account for over 88 percent of the total predicted hydrocarbon emissions. No hydrocarbons will be given off by the shale disposal operations. It will be assumed that scale up to a 100,000 bbl/day facility can be accomplished by simply multiplying the figures given by a factor of two. This is a reasonable assumption since doubling the size of the facility would involve doubling the number of retorting vessels. The hydrocarbon emissions for a 100,000 bbl/day retort facility, calculated on this basis, would then be approximately 245 kg/hr with emission control and about 435 kg/hr without. Since emission control consists only of a hydrocarbon incinerator (USDI, 1975), which is a relatively simple mechanism, it is reasonable to surmise that the hydrocarbon emissions will be under control almost continuously during operation. The BaP content of the hydrocarbon emissions has not been reported in the literature. Therefore, it will be assumed that the BaP content of the hydrocarbon gases is similar to that of the raw shale oil. The basis for this assumption lies in the fact that both the hydrocarbon gases and the raw shale oil are products of kerogen pyrolysis. The gases of course, will contain a greater proportion of light distillates. However, Hueper and Cahnman (1958) have shown both the light and heavy fractions of shale oil to be carcinogenic. The assumption may perhaps result in an overestimation of the amount of BaP present in the gases, as BaP volatilizes at relatively high temperatures. However, since the BaP is being used only as an indicator of carcinogenicity, the assumption may be valid when used in assessing the carcinogenic nature of the hydrocarbon emissions.

The proportion of BaP in raw shale oil is shown in Table 3 to lie between 30,000 and 40,000 parts per billion (ppb). An intermediate value of 35,000 ppb was chosen as representative. Applying this figure to the hydrocarbon emission rate of 245 kg/hr results in a predicted release of 8.58 g/hr of BaP to the atmosphere, or about 75 kg/yr. These releases will be a chronic source of BaP as well as other potential carcinogens. Since they are in a volatilized form, they can be expected to be free to interact in the environment.

No calculations of the actual amount of spent shale dust that is expected to enter the atmosphere near the shale retort and disposal sites have been made in other literature. Therefore it is necessary to make an assumption concerning the dust emissions. The quantities of spent shale dust released to the atmosphere surrounding the retort and disposal sites will be equated to the predicted particulate emissions from these areas. This supposition follows from the realization that particulate emissions from the retort facility originate primarily from the ball separator where spent shale is screened from 1/2 inch ceramic balls, and that disposal site particulates are primarily spent shale particles escaping into the atmosphere.

Particulate emissions predicted to occur from the Colony development site are shown in Table 5. The preheat and elutriator systems, as well as the shale wetter are of interest here. These three units emit over 85 percent of the total particulates shown. Scale up to a 100,000 bbl/day operation results in a predicted emission rate of approximately 640 kg/hr of particulates from these sources under controlled conditions.

Table 5. Average expected particulate emissions for the proposed Colony Shale Oil Plant (taken from USDI, 1975).

Sources loacted at plant site	No. of Stacks	Total PM emission rates for all stacks kg/hr	Without dust suppression equipment kg/hr
Preheat systems	6	110.4 112.7	5,187
Elutriator systems	6	98.1 109.1	
Coker heater	1	0.5 0.5	0.5
Gas-oil reactor feed heater	2	0.2 0.2	0.2
Gas-oil reboiler furnace	1	0.7 0.8	0.8
Naphtha reactor feed heater	1	0.09 0.09	0.09
Hydrogen reforming furnace	4	5.2 5.8	5.8
Boilers (auxiliary)	2	1.3 1.4	1.4
Sulfur plant tail gas unit	1	0.0 0.0	0
Shale wetter	6	110.4 122.7	272
Fine ore storage	1	1.9 2.1	701
Fine ore crusher	4	15.0 16.6	5,392
Coarse ore crusher	1	3.6	1,292
Portal transfer point	1	0.45	0.45
Feed bin transfer point	1	2.7	2.7
Reclaim tunnel transfer point	1	2.7	2.7
Mine ventilator	3	20.4	20.4
Total for plant site	42	373.6 382.0	12,870
Sources Located at Grand Valley			
Utility boilers	2	0.05	
Total for Both Sites	44	373.7 382.4	

Note: Emission rates on first line are normal, rates on second line are peak values.

This figure rises to 10,920 kg/hr if control devices are removed. The bulk of this increase would arise from the retort facility emissions. Particulate removal here will be accomplished through the use of a high energy Venturi wet scrubber (USDI, 1975). This unit is essentially non-mechanical and will probably not be subjected to frequent, prolonged breakdowns. Therefore it can be theorized that the particulate emissions during actual operation will approximate the predicted values under controlled conditions.

Values for the BaP content of spent oil shales are given in Table 3. The figures relating to shale from the TOSCO II process range from 13 to 100 ppb, differing by an order of magnitude. The 100 ppb concentration was analyzed by the Kettering Laboratory under contract to Colony and it will be used because of its conservative nature. Calculations carried out on this basis indicate that about 0.064 g/hr, or 560 g/yr of BaP will be carried into the atmosphere with particulate emissions from the shale retorting and disposal sites. This dust will be another chronic source of BaP in the environment. However, the BaP here will be contained in the carbonaceous coating on the spent shale and in this form it may not be able to interact freely in surrounding ecosystems.

The vapors arising from the volatilization of hydrocarbons contained within the spent shale piles may contain BaP as well as other carcinogenic compounds. The ambiguous nature of the occurrence and extent of these releases renders exact quantification impossible. Factors such as ambient air temperature, wind velocity, pile temperatures, quantity of vegetation on the pile, pile surface area and pile moisture content will all interact in this area. Auto-oxidation of the residual organic

materials within the pile is possible (Schmidt-Collerus, 1976) and this phenomenon could add significant amounts of heat to the spent shale. This heat, when combined with that from solar radiation, could cause extensive volatilization of hydrocarbon compounds, including the carcinogens. If it is assumed that five percent of the hydrocarbons added to the pile each year become volatilized, this would introduce 175 kg/yr of BaP into the atmosphere based on calculations presented on page 42. This would be more than twice the amount released into the atmosphere from the retorting facility.

Statement on pg 37 indicates it takes high temperatures to volatilize BaP. Is the 5% a realistic number?

may be too strong of wording when compared to the assumptions made.

Thus, the potential for very significant releases of carcinogens into the atmosphere lies within the volatilization of hydrocarbons in the spent shale. When released in this manner the organic carcinogens could be expected to be in a potentially reactive form.

The atmospheric emissions of BaP and other organic carcinogens will, in general, be a chronic source of potentially carcinogenic material in the environment surrounding the shale retorting and disposal sites. Emissions from the retort facility will exist only as long as the plant remains in operation. Vapors may continue to rise from the spent shale piles long after shutdown occurs. However, volatilization can be expected to become less intense with time as the volatile compounds are removed from the pile surface.

The concentration of BaP in the surrounding atmosphere, based on Colony's prediction of a maximum mean annual hydrocarbon level of 4.8 $\mu g/m^3$ (USDI, 1975) would be near 1.7×10^{-4} $\mu g/m^3$. This figure is derived when only retort facility emissions are considered. Conceivably,

it could be as much as doubled or tripled by shale pile vapors. A consistent five percent volatilization rate would raise the concentration of BaP to perhaps 5.7×10^{-4} $\mu g/m^3$. This seems to be a low level. However, its presence would be chronic and it is uncertain as to what a ''safe'' level actually is. Also, increased development of oil shale would increase the load of carcinogens in the atmosphere in approximate proportion.

Water Emissions

The ultimate source of contamination of any water emissions emanating from the development site will be the spent shale piles. All process and wastewaters produced will be collected and used for moisturizing the spent shale. This includes retort water contaminated by intimate contact with the pyrolysis products as well as runoff water from the retort site which may contain spilled shale oil as well as shale particles. The spent shale piles will also act as disposal sites for all of the solid waste generated during plant operation (USDI, 1975). The major solid wastes that will be disposed of on the piles are shown in Table 6. Therefore the spent shale piles will harbor a tremendous reservoir of potentially carcinogenic organic compounds. One year's production of spent shale alone, which is the only constituent analyzed to date, containing 100 ppb BaP, will embody 3,500 kg of this compound. The question now becomes whether or not this potentially carcinogenic material will make its way from the shale disposal area into the surrounding environment.

Water is the most obvious transport medium for carrying these materials into the ecosystem. Precipitation falling on the pile may leach

Table 6. Major solid wastes to be disposed of in spent shale piles (taken from USDI, 1975).

Source of Solid Waste	Approximate Quantity	Annual Production	Major Constituent
Pyrolysis Unit			
Processed shale	53,200 T/D[a]	19,418,000 T	Processed Shale
Clarifier sludge from wet scrubbers-Preheat System	860 T/D[a]	313,900 T	Raw Shale Dust
Ball circulation system	65 T/D[a]	23,725 T	Processed Shale Dust
Processed shale moisturizing system	43 T/D[a]	15,695 T	Processed Shale Dust
Total	54,168 T/D		
Crushing Unit			
Primary crusher	25 T/D	9,125 T	Raw Shale Dust
Final crusher	325 T/D	118,625 T	Raw Shale Dust
Shale storage silo	75 T/D	27,375 T	Raw Shale Dust
Total	425 T/D		
Upgrading Units (Hydrotreaters)			
Naphtha	0- 75 T/2 yrs (max)	0- 75 T	Spent HDN Catalyst
Naphtha	60 T/yr	60 T	Proprietary Solid
Gas oil	0-260 T/2 yrs (max)	0-130 T	Spent HDN Catalyst
Gas oil	350-475 T/yr	350-475 T	Proprietary Solid
Hydrogen Unit			
Hydrodesulfurizer	135 T/3-5 yrs	34 T	Spent HDS Catalyst
Caustic wash	2.4 T/D	876 T	Spent Aqueous Caustic
Guard bed	15 T/1-3 yrs	7 T	Spent ZnS Catalyst
Shift converter (high temp.)	50 T/5 yrs	10 T	Spent Fe-Cr Catalyst
Shift converter (low temp.)	50 T/3 yrs	16 T	Spent Cu-Zn Catalyst
Sulfur Unit			
Claus unit	150 T/2 yrs	75 T	Spent Bauxite Catalyst
Tail gas hydrotreater	10 T/5 yrs	2 T	Spent Co, Ni-Mo Catalyst
Gas Treating Unit			
DEA filter	8.25 T/2 weeks	429 T	Diatomaceous Earth
DEA filter	8.25 T/2 weeks	429 T	Deactivated Carbon
Coker Unit	800 T/D	292,000 T	Green Coke
Water Treatment	1,200 lbs/day	219 T	Lime and Alum Flocculants
	50 lbs/day	9 T	Proprietary Coagulant Aid

[a]Water Excluded.

into it or run off. In either case the water is likely to pick up concentrations of the organic materials contained in the shale pile. Schmidt-Collerus (1974) feels that it is plausible to expect groundwater and/or runoff water to solubilize carcinogenic compounds present in carbonaceous spent shale to a considerable extent. He also expresses the opinion that the stronger the carcinogenicity of a compound, the higher is its solubility in water. Quantitative determinations of potential carcinogens picked up by shale pile runoff or leachates have not, as yet, been made. However, it is reasonable to expect that these waters will carry a potent carcinogenic threat. Leachates from the piles which find their way to groundwater systems would constitute a chronic source of contamination, not only to groundwaters, but also surface waters. Runoff would occur only during periods of snow melt or rain and would thus exhibit shock loading characteristics on local watercourses.

Colony has recognized the potential hazard of these water emissions and has proposed to mitigate them by minimizing percolation of water from the shale pile into underlying groundwater and by committing itself to zero surface water discharge from the development site (USDI, 1975). Since these measures do not involve any new or complex technologies, but merely the application of basic engineering principles, it can be expected that other shale development companies would implement similar designs for surface retort facilities.

Alleviation of groundwater contamination will be accomplished by stripping the existing soil layer from the disposal area and placing the spent shale directly on underlying rock strata. Colony believes this

action will prevent significant amounts of water from percolating through or passing under the pile. This measure, however will not completely eliminate contamination of the underlying groundwaters and in areas where it is not possible to remove the existing soil layer, extensive groundwater pollution could occur. Chronic contamination of the area groundwater is therefore inevitable and subsequent contamination of surface waters may ensue. The levels of organic carcinogens that will be induced by this contamination are not determinable at this time.

The direct contamination of area surface waters by runoff from the shale piles will be prevented by complete containment of all waters running off from the site watershed. This containment will be accomplished on the Colony site by construction of a drainage system and catchment dam as shown in Figure 8. The dam would be designed to hold runoff from a probable maximum thunderstorm of 6.5 inches per hour, and will be filled with an emergency spillway which would release its overflow to nearby watercourses. Water stored behind the dam would be utilized as a moisturizer for the processed shale (USDI, 1975). Colony admits that failure of the dam would cause a severe degradation of the receiving stream with the unavoidable loss of aquatic life. Spillway overflow would certainly be possible at times of snow melt combined with heavy precipitation. The extensive release of potential carcinogens at these times would be unavoidable. Once again, a quantitative evaluation would be impossible.

The real concern, however, evolves as time passes beyond the productive use of the processing facility. Colony, for example, plans to maintain the catchment dam only through the expected 20 year life of the

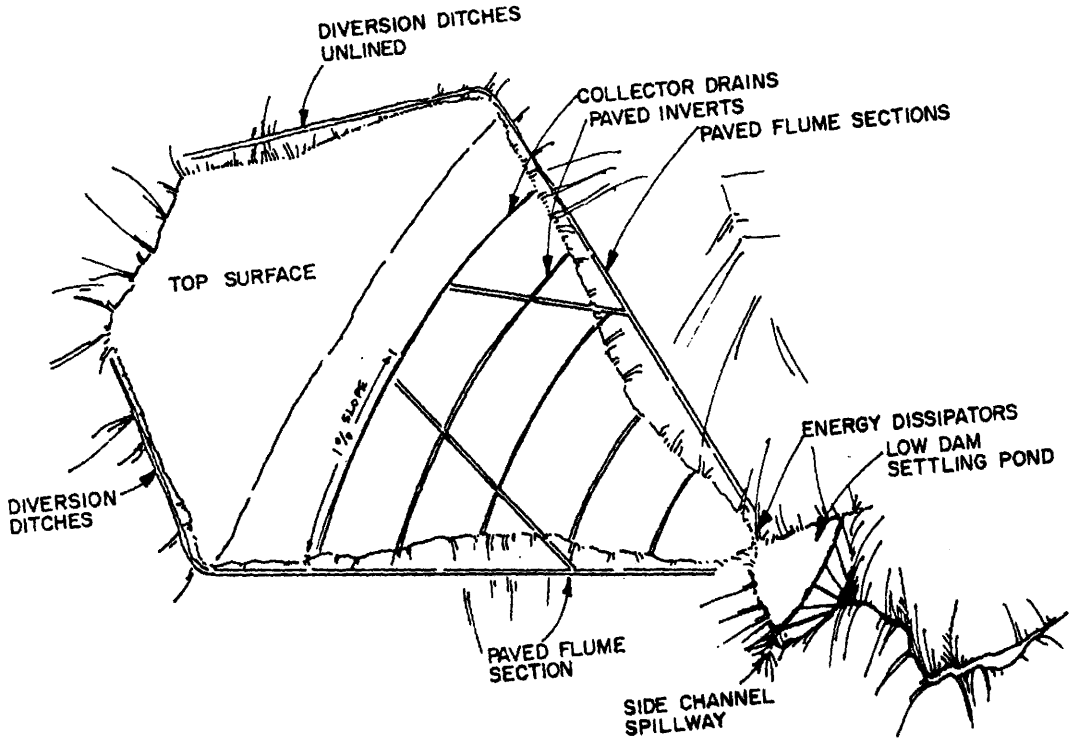

Figure 8. Drainage system of processed shale pile (taken from USDI, 1975).

plant. The dam would then be removed if it was not sold (USDI, 1975). The flow of carcinogens from the spent shale pile into area watercourses would then be uncontrolled. The effects of these discharges could devastate the aquatic ecosystem. Carcinogens in both solubilized and adsorbed form would flow freely into the environment with runoff waters. This influx might induce chronic uptake effects on downstream water users. The piles would remain as sources of carcinogenic material for years after shale production had ceased.

Certain assumptions will need to be made in order to evaluate potential quantities of BaP which could be carried into the environment with water which runs off or percolates through the spent shale piles despite the precautions taken by industry. As time goes on, the piles will, of course, become larger and larger until the disposal site is filled or the plant shuts down. A 100,000 bbl/day retorting facility would add 19.5 million tons of shale containing 3500 kg of BaP to the disposal area each year. Thus, as the facility continues to operate, more and more BaP would be present in the pile and available for transport into the environment. After 20 years of operation almost 400 million tons of spent shale with 70,000 kg of BaP will be deposited. The shale most recently disposed will lie on the surface of the pile and be most exposed to both runoff and percolating water.

The assumption will then be made that five percent of the organic compounds, including the carcinogens in direct proportion, present in each year's spent shale production will somehow be transported into the environment by water during the respective year of production. The five percent figure is believed to be a reasonable estimate of the proportion

available for transport. Schmidt-Collerus (1974) reported that 20 percent of the bezene extractable organic material present in spent shale could be extracted with water. BaP is a benzene soluble compound and therefore would likely be included in this 20 percent. Thus the assumption conservatively estimates that about one fourth of the available BaP will be carried off by water despite the precautions taken by industry to prevent such an occurrence. This assumption refutes industry's contention of complete containment of runoff and leachates from the spent shale piles. It is made with the realization that no containment scheme could be absolutely perfect and that a reasonable estimate of the quantity of contaminants which are somehow transported by water into the environment needs to be made.

It was also assumed that the percent of the available BaP taken from shale deposited in each preceding year will decrease exponentially with the inverse of the base of the natural logarithm taken to the power of the age of the spent shale in years. The mathematical formulation for this relationship can be expressed as follows:

$$X = k \sum_{t=1}^{n} e^{-(t-1)}$$

where

X = the amount of BaP transported into the environment during any given year in kg

k = a constant equal to five percent of the BaP present in one year's production of spent shale (175 kg)

n = the integer number of years the shale plant has been in operation up to the year of concern. $1 \leq n \leq 20$

Thus the amount of BaP carried by water from the shale pile into the environment during the fifth year of operation would be estimated by the following calculation

$$X = 175[e^{0} + e^{-1} + e^{-2} + e^{-3} + e^{-4}] = 275.0 \text{ kg}$$

The amount of BaP, in kilograms, transported into the environment by water during each year of the expected 20 year plant life based on these assumptions is given in Table 7. From this table it can be seen that a value of 275 kg/yr would be a reasonable estimate of the amount of BaP escaping into area watercourses over the life of the shale facility.

If it is further assumed that the shale development takes place in the State of Utah, and that all of this BaP reaches the White River in proportion to the flow of the river, an overall yearly concentration of

Table 7. BaP transported from spent shale piles into surrounding watercourses during each year of retort facility operation.

Year number	kg of BaP
1	175.0
2	239.4
3	263.1
4	271.8
5	275.0
6	276.2
7	276.6
8	276.8
9	276.8
10	276.8
11	276.8
12	276.8
13	276.9
14	276.9
15	276.9
16	276.9
17	276.9
18	276.9
19	276.9
20	276.9

BaP in the river waters, based on an annual flow of 500,000 acre-feet/yr (USDI, 1973) would be 4.51×10^{-4} mg/l.

Shale Oil

Tremendous quantities of carcinogenic materials will be carried from the retort facility in raw shale oil. The BaP content of the oil, as previously mentioned, is on the order of 35,000 ppb. The raw shale oil has been proven to be potently carcinogenic (Scott, 1922; Leitch, 1922; Kennaway, 1924; and Hueper, 1953).

However, modern processing technologies have virtually eliminated human contact with the shale oil. Good personal hygiene practices will probably eliminate the carcinogenic threat of sporadic contacts. Oil which is accidentally spilled from the closed transport systems will be ultimately disposed of in the spent shale piles if it is not recovered (USDI, 1975). Its carcinogenic potential will then be added to the myriad of other substances already there. Thus, the raw shale oil, in itself, will not act as a significant mechanism for the transportation of carcinogenic compounds from the shale retorting and disposal sites into the environment.

Overall Assessment

The sources and sinks of BaP from a TOSCO II retorting facility are shown in Figure 9. Also shown are the potential flow routes for the transport of BaP. The figures shown for quantity of flow are assumed to be values reached once a steady state has been established.

Will steady state ever be reached? If the spent oil shale piles act as a large sink and surface water is essentially completely contained and percolation is near zero, the slow release from spent oil shale may never reach steady state conditions

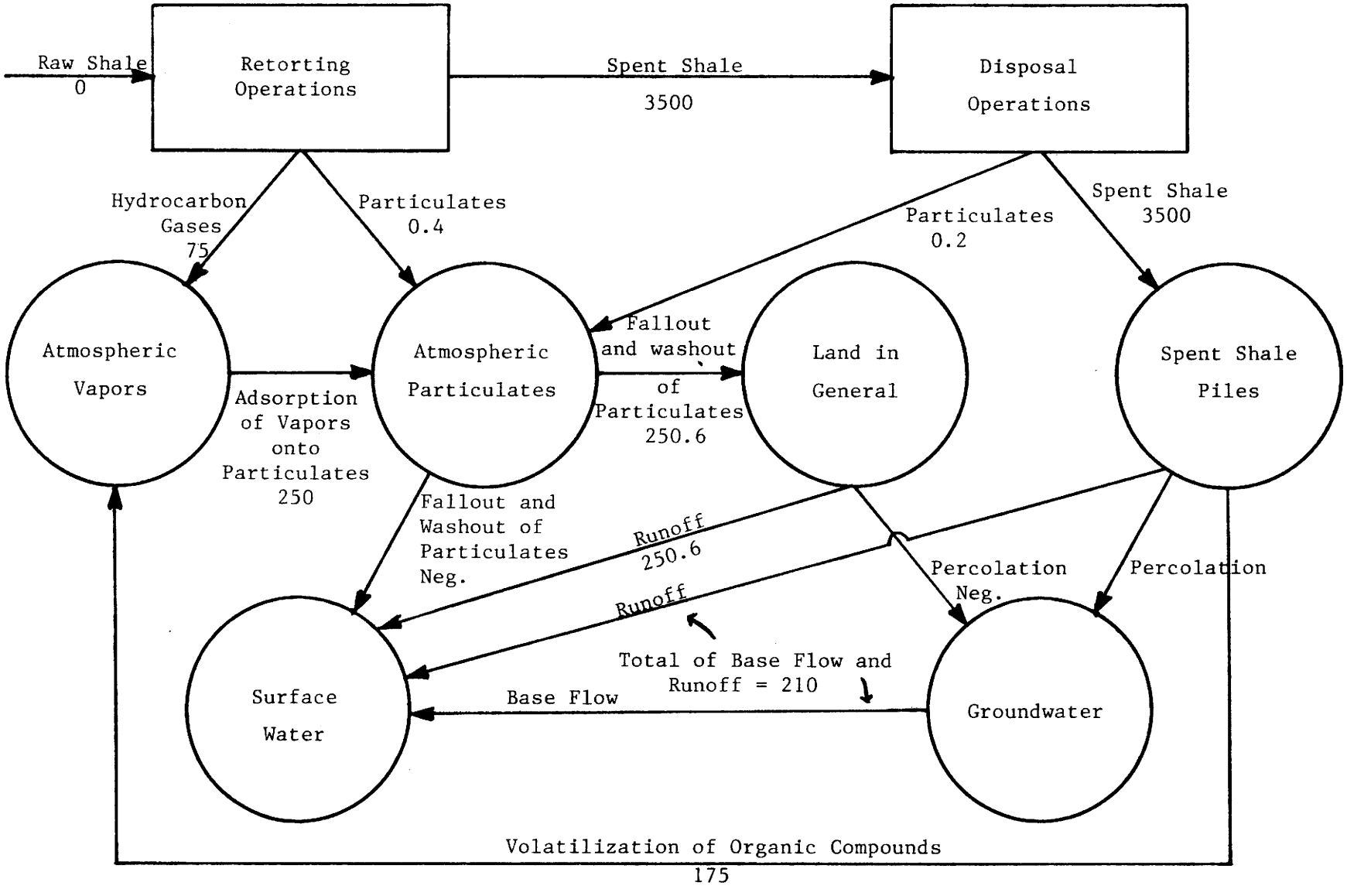

Figure 9. Flow of BaP from a 100,000 bbl/day TOSCO II retorting facility. Figures in kg/yr.

Therefore, a constant buildup of BaP will occur in the spent shale piles as well as in the surface waters. Other sinks may accumulate BaP up to a point before a steady state is established. Flow pathways for BaP fallout and washout onto the earth with particulate matter and subsequent runoff from the land into surface waters are shown but have not been previously discussed as the other flow patterns and figures have been.

As can be seen, it was assumed that all vaporized BaP entering the atmosphere will be adsorbed onto airborne particulate matter, a removal mechanism suggested by Reynolds (1976). It was then further assumed that all particulates would either fallout or be washed out of the atmosphere onto the land and would subsequently be carried into the surface waters by runoff. This runoff would have the potential, then, of carrying as much BaP into the surface waters as the assumed pile runoff and percolation.

The surface waters, therefore, would become the final collection site for any BaP which enters the environment once steady state conditions had been established. This is an important consequence as the surface waters will have the ability to transport the BaP over great distances, even if it is entirely absorbed by the aquatic food chain.

It should be noted once again that all of the figures are based on calculations made assuming the operation of a 100,000 bbl/day TOSCO II retorting and spent shale disposal facility as envisioned by the Colony Development Operation. Other retorting technologies, and perhaps even various companies employing the same technology could create different emissions to which a different set of assumptions would apply.

INTERACTIONS IN ECOSYSTEMS

Introduction

Standards spelling out ''safe'' and ''non-safe'' levels of most carcinogenic materials such as BaP in air, water and food have not yet been established (Ember, 1975). Therefore, it is difficult to determine the exact effect that the chronic, low level emissions of these compounds from oil shale development sites will have on organisms in the surrounding environment or on man. However, the application of certain assumptions will allow for a tentative analysis of the fate of these compounds within the ecosystem.

The basic assumption made was that BaP, as well as the other shale carcinogens, would be accumulated and concentrated in both aquatic and terrestrial food chains much in the same manner that DDT is. The relation to DDT will be employed because there is substantial data available on the biomagnification of DDT in ecosystems. The only real basis for the assumption lies in the fact that both DDT and BaP are organic compounds containing benzene rings. Also, both are benzene soluble while being practically insoluble in water (Merck Index, 1968).

Inherent in the assumption that BaP will be accumulated and concentrated in food chains in a manner similar to DDT is the presumption that BaP will somehow be taken up by organisms in the ecosystem.

It will be assumed that the only source of BaP for organisms existing in the aquatic environment will be the waters which surround them. It is reasonable to expect that BaP existing in the air or on the land

would have negligible effects on organisms living in the aquatic environment. Uptake of BaP in the aquatic ecosystem directly from surrounding waters will be assumed to take place only at the level of photosynthetic organisms (primary producers). Higher trophic level organisms will ingest BaP when feeding on lower level organisms which have accumulated the compound. This assumption will simplify the analysis and is based on the supposition that there will be enough producing organisms present in the system to remove essentially all of the available BaP from the water and thus prevent it from reaching higher level organisms by direct uptake mechanisms.

Terrestrial ecosystems were viewed in a different manner than the aquatic systems were. It was assumed that producing organisms in the land based system would not, in general, take the shale site BaP up into their systems and transfer it into the food chain. This assumption is based on the expectation that only vegetation actually growing on the spent shale piles will have enough BaP available for significant uptake to occur through its root system. It is assumed that revegetation will be required to stagilize the spent shale piles. However, the amount of vegetation growing on the spent shale piles will be small when compared to the total amount of vegetation in the area. The Colony spent shale disposal site is expected to cover 1.25 square miles of land (USDI, 1975). The figure may appear to be quite large, but when related to the land area of the Piceance Creek Basin of Colorado (USDI, 1973) it represents only about 0.1 percent of the total. Also, since the disposal piles would be a major area of human activity, grazing on this vegetation would be controlled or be minimal. Therefore the effects of this small

amount of vegetation on the overall terrestrial food chain would be negligible.

The higher level terrestrial organisms were assumed to take in BaP primarily by ingestion with their food. In the case of herbivores, ingestion of BaP attached to particulates which have fallen or washed out of the atmosphere and have settled on the surface of the vegetation they graze would be the primary uptake mechanism. Carnivores would then ingest and magnify the BaP when feeding on the herbivorous organisms. The uptake of BaP by terrestrial animals in their water and air will be ignored since it is likely a minimal increment addition. It can be expected that the total quantity of BaP ingested from these two sources will be rather low because of the low concentrations present. This assumption is supported by the calculations carried out for human BaP uptake presented in a subsequent section.

Aquatic Ecosystem

The food chain in an aquatic ecosystem consists, in general, of four trophic levels. The lowest level consists of the producing organisms, aquatic plants and algae. The second level consists of primary consumers, or herbivores, and includes organisms such as insects and zooplankton which feed on the producers. Secondary consumers, or general carnivores, make up the third trophic level. This group would include larger insects, minnows and small fish which feed on the two lower trophic levels. The highest trophic level is occupied by the tertiary consumers, or top carnivores. In an aquatic ecosystem large fish would exist at this level.

The phenomenon of accumulation and concentration of a pesticide such as DDT within a food chain is known as biomagnification. The effect of biomagnification in a food chain such as the one described has been shown by Robinson et al. (1967) to increase the concentration of DDT by a level of magnitude between trophic levels as indicated in Table 8. In other words, passing from organisms in the first level to organisms in the fourth level would magnify the concentration of DDT by 1000 times.

This model was applied to the ecosystem of the White River in Utah. Figure 9 shows 460.6 kg/yr of BaP flowing into surface waters. If it is assumed that this entire amount of BaP were to uniformly enter the White River, which has an average annual flow of approximately 500,000 acre-feet (USDI, 1973), the average annual concentration of BaP in its waters would be about 7.56×10^{-4} mg/l.

Table 8. Pesticides in a marine ecosystem (taken from Robinson et al., 1967).

Trophic Level	Species Involved	DDT
Tertiary consumers (top carnivores)	Dolphin	1.0
	Seal	0.1
	Duck	
	Gull	
	Shag	0.1 to 1.0
	Cormorant	
	Gannet	
		0.01 to 0.1
	Plaice	
Secondary consumers (general carnivores)	Herring	
	Sand eel	
	Cod	
	Whiting	
Primary consumers (herbivores)	Microzooplankton	0.01
Producers (plants)	*Fucus*	0.001
	Laminaria	

It was further assumed that the producing organisms in the system would reach an equilibrium level of BaP concentration in their cells nearly equal to that of the surrounding waters, as is the case with DDT (Robinson et al., 1967). This, of course, would result in a BaP concentration of 0.756 ppb within the producers. The herbivores might then accumulate BaP to a level of 7.56 ppb in their tissues. Concentrations in general carnivores living in the White River could reach 75.6 ppb. The top carnivores in the ecosystem could accumulate concentrations of up to 756 ppb in their bodies.

Another assumption made to facilitate the human carcinogenic evaluation was that these projected levels of BaP will be uniformly distributed throughout the tissues of the organisms. It was recognized that certain tissues, especially fatty tissues, might act as storage sites for BaP while others could remain essentially free of BaP. The lack of information regarding areas of BaP storage within organisms prevented a more precise analysis of BaP distribution.

Terrestrial Ecosystems

The food chain in a terrestrial ecosystem can, in general, be viewed much in the same way as the aquatic food chain. However, it probably could be better approximated by three, instead of four trophic levels. Therefore, the levels to be considered are the producers, herbivores and carnivores, with the elimination of one carnivorous level.

It has already been assumed that terrestrial producers will not take BaP into their systems in amounts sufficient to affect the food chain. Terrestrial herbivores will ingest BaP which is contained within

atmospheric particulates which have settled on the vegetation they graze. Carnivores feeding on these herbivores will then take in and magnify the BaP concentration.

In order to simplify this assessment only one herbivorous terrestrial organism was analyzed for BaP uptake through grazing. The organism studied was the cow. It was chosen because it is a source of both meat and dairy products for man and would therefore act as a definite link in the human food chain. It can also be expected that along with oil shale developments will come an increase in the number of domestic grazing animals in the shale area and a decrease in natural grazing wildlife. The cow, then, will be a long term herbivore residing in the shale development area. Why expect an increase in grazing animals in the oil shale areas? In three years of work on oil shale lands, I have yet to see my first cow on either Ua or Ub.

Certain further assumptions needed to be made in order to evaluate the BaP uptake of a cow grazing on vegetation in the vicinity of a shale development site. The first assumption made was that the entire quantity of BaP introduced into the atmosphere during one year of plant operations will be present in the particulate fallout which settles in a uniform concentration within a five mile radius of the plant site. This was a simplifying assumption since the actual distribution downwind of a stack probably decreases exponentially and fallout would be greatly dependent on wind speeds, wind direction, and other atmospheric conditions. This level of BaP was also assumed to be the equilibrium level established due to fallout on the land and will therefore be continuously present.

Thus, 250.6 kg of BaP would be distributed over a 78.5 square mile area. This results in a density of about 3.2 kg/mi^2.

Vegetation in the vicinity of the shale development sites is sparse and provides about 15 percent ground cover (USDI, 1975). This means that about 0.48 kg of BaP would be present on the particulate matter which settles onto the surface of vegetation in each square mile of land.

The Colony Development Operation (USDI, 1975) has determined that a cow living in the shale development area would require about 4 acres of land per month for grazing purposes. Thus an average cow would graze about 50 acres of land per year, and the affected area could support about 1000 cows. These figures do not fit Utah Tracts at all. There are 158 cows grazing on the bottom lands of the White River from 6-1 to 10-31. This allotment will be discontinued when the dam is built on the river, flooding the bottom lands. (Unpublished data, BLM, Vernal)

It was further assumed that the cow would live exclusively within the five mile radius area for one year and would ingest one percent of the BaP which had settled with particulates onto the vegetation within its grazing area. The one percent figure was used in order to offset some of the overestimations that may have resulted from previous assumptions. Thus, the hypothetical cow could ingest 0.37 gm of BaP with its food each year–[(0.48 kg BaP/mi^2)(1 mi^2/640 acres)(50 acres/yr)(1000 g/kg)(0.01) = 0.37 g].

If the cow were to retain within its body all of the BaP taken in during grazing, one year's consumption would result in an overall tissue concentration of 620 ppb. This figure is based on an average cow weighing 600 kg (World Book, 1975).

The figure of 620 ppb of BaP within the body of a cow which had grazed for one year in the oil shale development area could probably be related to other terrestrial herbivores feeding in the vicinity. Actual concentrations might vary by as much as an order of magnitude or more

among various species but the figure gives a rough estimate of the consequences of the shale site emissions.

The 620 ppb level of BaP in the tissues of terrestrial herbivores will be assumed to be a steady state concentration. This assumption will also help to alleviate some of the overestimations which may have resulted from the previous assumptions.

Terrestrial carnivores will magnify the levels of BaP present in the herbivores. The extent of this magnification cannot be directly related to the biomagnification which occurs in aquatic food chains since the terrestrial will not be forced to subsist on a steady diet of animals in lower trophic levels which have taken up BaP. The terrestrial carnivores will be able to feed on herbivores living outside the shale development area as well as those living within it. Therefore, it will be assumed that they will concentrate BaP only five times, rather than 10 times in their systems. Thus the level of BaP in terrestrial carnivores might be approximately 3100 ppb.

HUMAN EXPOSURE TO CARCINOGENS

Introduction

''Man encounters potentially carcinogenic substances in every part of his environment'' (Baldwin and Matthias, 1970, p. 116). This quotation illustrates the dilemma man finds himself in when trying to pinpoint the causes of human cancers. It has been estimated that 60 to 90 percent of all human cancers are caused by environmental factors (Ember, 1975). Yet, the exact causative agents of these cancers are relatively unknown. Of the more than two million chemicals known to man, less than 6000 (0.3 percent) have been tested for carcinogenic activity and only 32 are known to be carcinogenic to man (Ember, 1975). If the proportion of known human carcinogens is the same in the untested compounds as it is in those already tested, there are over 10,000 as yet unidentified substances in the environment which are human carcinogens.

Man, therefore is faced with the uncertainty of not knowing whether some of the 99.7 percent of the substances he is exposed to are causative agents of cancer. It is little wonder that the Schmidt-Collerus (1974) report, which revealed that literally tons of known carcinogenic materials would be introduced into the environment with the wastes of oil shale industries, caused a furor among the populations of the shale states.

The purpose of this section will be to attempt to place some perspective on the possible human uptake of carcinogens present in emissions from an oil shale retorting and disposal site. A critical path approach based on judgment and not systems analysis will be used in this evaluation.

Critical Path

The critical path approach to the assessment of the human carcinogenic hazard will be employed to evaluate the maximum flow of BaP into a human being under what are considered to be ''worst case'' conditions. The worst case approach is based on the absence of counter information specific to the oil shale ecosystem. Processes such as photolytic or biological degradation would reduce the concentration of BaP but in this analysis BaP is being used as an indicator or tracer and in the interest of minimizing hazard is being treated as a conservative substance. The hypothetical human will spend 20 years in the shale development area breathing only air with the maximum BaP concentrations, drinking only untreated water from the White River, and having as his only sources of fish and beef the top carnivores of the White River and the cows which graze within a five mile radius of the development site. Finally it is assumed that he will retain within his tissues all of the BaP he takes up. The maximum theoretical flows of BaP into such a human being are shown in Figure 10.

The hypothetical human will be assumed to be a ''standard man'' as defined in the Radiological Health Handbook (USDHEW, 1970). He will also be assumed to consume the amount of meat that the average American does, with the proportion of beef and fish in his meat diet also being the same as the average Americans'.

A standard man breathes about 22.8 cubic meters of air each day. Therefore, this hypothetical human will inhale 4.74 g of BaP each year and about 95 µg over a period of 20 years-[$(5.7 \times 10^{-4}$ µg/m^3)(22.8 m^3/day)

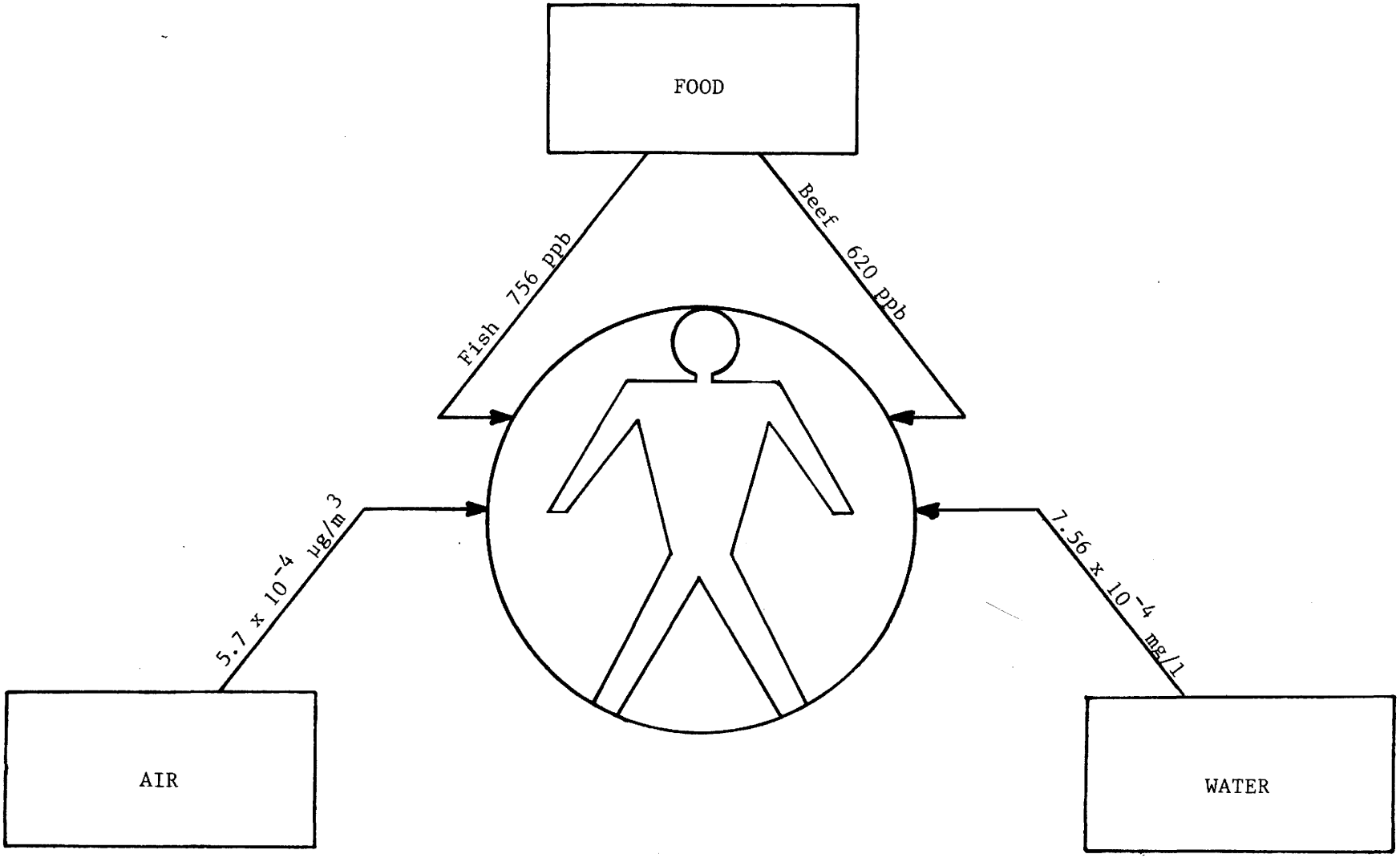

Figure 10. Flow of BaP into standard man living in oil shale development area.

(365 days/yr)(20 yr) = 94.9 μg]. If this quantity of BaP were to distribute itself uniformly throughout his entire body it would result in a concentration of 1.36 ppb, based on a weight of 70 kg for the standard man. However, if this entire amount of BaP were to remain within his lungs, which weigh about 1 kg, the concentration in those tissues would be 95 ppb.

See following page

The water intake in the diet of standard man is one liter per day. Assuming all of this water were to come from the White River with a BaP concentration of 7.56×10^{-4} mg/l, the hypothetical man would drink about 0.28 mg of BaP each year for a total of 5.52 mg in 20 years-[$(7.56 \times 10^{-4}$ mg/l)(1 l/day)(365 days/yr)(20 yr) = 5.52 mg]. The 5.52 mg of BaP distributed throughout the 70 kg of body would result in a level of 79 ppb. If this entire quantity of BaP were to be retained solely within the liver, which weighs 1.8 kg in standard man, the concentration of BaP in this organ would be approximately 3 ppm.

See following page

The average American consumes 114 kg of meat per year of which 53 kg are beef and 6 kg are fish (USDA, 1975). The hypothetical man would therefore ingest about 657 mg of BaP with the beef in his diet over a period of 20 years-[$(620$ g/ 1 $\times 10^{9}$ g)(53,000 g/yr)(20 yr)(1000 mg/g) = 657.2 mg]. During this same period he would ingest approximately 90.7 mg of BaP with the fish in his diet-[$(756$ g/1 $\times 10^{9}$ g)(6000 g/yr)(20 yr)(1000 mg/g) = 90.72 mg]. This would bring the total intake of BaP with the beef and fish in his diet to almost 750 mg in 20 years. Uniform distribution of this BaP throughout his body would result in a concentration of about 10.7 ppm. Retention solely within his liver would concentrate BaP to 416 ppm in that organ.

The BaP level in the body of the hypothetical man caused by uptake of the compound through the food chain dwarfs the concentrations brought about by inhalation of the contaminated air or consumption of water containing BaP. The case chosen, was as previously mentioned, the ''worst case.'' If it is now assumed that a less severe exposure takes place, say the hypothetical man obtains only 10 percent or one percent of his beef and fish from animals in the shale area, then the overall body concentrations and actual moles of BaP contained within the body shown in Table 9 result.

Table 9. Concentrations and molar quantities of BaP within a hypothetical man who has obtained various percentages of the beef and fish in his diet from animals living within the shale development area for a period of 20 years.

Percent of beef and fish obtained from shale area animals	Total body BaP Concentration (ppm)	BaP Quantity (μmoles)[a]
100	10.7	2970
10	1.07	297.0
1	0.107	29.70

[a]Molecular weight of BaP = 252.3.

The oil shale area (Ua & Uo) of Utah is not cattle country, nor is the White river a prolific fish producer. To equate a hypothetical man eating a nonexistent beef or one of the few catfish in the White river, or obtaining his watersupply from untested water, or for that matter, living in a desolate area and breathing the polluted air for 24 hrs a day is beyond comprehension.

DISCUSSION

General

The figures calculated and presented in previous sections for BaP emissions from oil shale retorting and disposal sites and for resulting BaP concentrations in ecosystems surrounding the development area are not intended to be unequivocal. They are intended to quantify, albeit hypothetically, entities which have not been quantified before. They are intended to instigate further research into what the actual, real life values of these quantities might be, even if the sole purpose of the research is to refute the figures given here. Their ultimate purpose is to serve as a starting point for more definitive evaluation of the carcinogenic hazard that may be created when the commercial development of this country's oil shale resources becomes a reality.

Analysis of Major Assumptions Made

The first, and most basic assumption made was that the oil shale development facility would incorporate a 100,000 bbl/day TOSCO II retorting scheme. The assumption that a TOSCO II retorting facility will be present in first generation commercial oil shale technology is strong. It may not, however, be to the scale of 100,000 bbl/day. This figure is probably an upper limit. Nonetheless, the figures presented here could be scaled up or down in direct proportion to the size of the plant for rough approximations.

The assumptions upon which the calculations of the air emissions were based are, in general, fairly sound. An exception to this might be

the assumed volatilization of five percent of the organic material added to the spent shale piles each year. This figure has no real basis in any published literature or research and was chosen arbitrarily for the purpose of argument.

The assumed escape of some organic compounds into the environment with waters leaching through or running off the shale piles is practical. No containment scheme can be expected to operate at 100 percent efficiency. The equation used to quantify these releases of BaP was purely theoretical, although presumably reasonable. Once again, it was employed for the purpose of arriving at a presentable figure.

All of the BaP which entered the atmosphere in the form of hydrocarbon vapors was assumed to be adsorbed onto airborne particulate matter. The particulates were then assumed to be totally removed from the air by fallout and/or washout. Once the particulates had fallen and/or washed out of the atmosphere onto the land they were assumed to be carried by runoff into surface waters. The first assumption is not a documentable phenomenon. However, it is a likely method (Reynolds, 1976) for the removal of BaP from the atmosphere and was employed to handle the flow of vaporized BaP within the system. The second assumption, that all particulates are sooner or later washed or settled out of the atmosphere, is strong. The last assumption in this group of three is defensible from the point that particulate fallout will be small particles which will not be attached to the land surface and therefore could easily be picked up and carried away by surface runoff.

The assumption that BaP will interact within the environment in a manner similar to DDT is probably weak. It has no basis in the literature and was employed to facilitate the presentation of an argument.

Assuming that the surface waters in the area of the shale development site would act as the ultimate collection site for the steady state flow of BaP is reasonable. The BaP would, in essence, have nowhere else to go; as is shown in Figure 9.

The assumption that the entire amount of BaP which enters the aquatic ecosystem will be available to, and indeed taken up, by aquatic organisms is a ''worst case'' hypothesis. There are no data in the literature to support this assumption. However, there were no data available to support any other figure either.

The assumption that terrestrial herbivores would take up their most significant quantities of BaP with particulates which have settled out on the vegetation they graze, was borne out by the subsequent calculations. The one percent uptake of the fallout on grazed vegetation was intended to act as a ''fudge factor'' to alleviate some of the potential overestimation present in other assumptions.

Assuming that the cow would retain within its tissues all of the BaP it ingested was another ''worst case'' calculation. Chang (1943) found that rats studied excreted about 42 percent of the BaP which was administered in their diet. However, this took place under extreme dosages of the compound, not with the low level uptakes the grazing cow would be exposed to.

Also, as indicated by Rigdon and Neal (1963), some of the BaP might enter the milk of such a cow and could create a secondary hazard which could be important in the area dairy industry.

The assumptions made as to the flow of BaP into the hypothetical, critical man are all essentially sound if the figures upon which the quantitative assessment is based are sound. Certainly, the man will have virtually no protection from the BaP vapors in the air. His water treatment facilities will probably not remove the BaP from his culinary water. The flow of BaP through the food chain certainly will occur when it is introduced into the environment and taken up by organisms in lower trophic levels. Again, the total retention assumption led to a ''worst case'' calculation.

HUMAN CARCINOGENICITY

As previously mentioned, there have been no standards set as to what a ''safe'' or ''unsafe'' level of most carcinogenic materials within the environment might be (Ember, 1975). The reasons for this are many. Among the foremost is the fact that the induction of cancer in a test species of animal does not necessarily mean that the test substance is a human carcinogen (Clayson, 1962). Even the induction of cancer by a specific compound in known quantities under laboratory conditions is a highly variable occurrence. The incidence of cancer can be varied by using different test species and even in susceptible animals, only specific tissues may be sensitive to a particular carcinogen (Oberling, 1952). Clayson (1962) has shown that the dose given, the route of administration, the diet and the number of animals kept together can all influence the incidence of tumors. Thus, results obtained on test animals under controlled conditions are very difficult to extrapolate to human beings living in a relatively uncontrolled environment.

However, standards spelling out ''safe'' or ''unsafe'' levels of carcinogens in the environment need to be stated quantitatively. There are only two alternatives to this. One would be to allow the uncontrolled influx of carcinogenic materials into our environment to continue to occur much as it has done in the past. The price we will pay under these conditions is illustrated by the already high levels of cancer incidence which occur in the polluted environments surrounding the major cities in this country (Ember, 1975). This solution, to say the least, is socially unacceptable.

The second alternative to establishing ''safe'' levels of carcinogenic materials in the environment would be to totally prevent the influx of materials suspected to be carcinogenic into all ecosystems. Whether or not it is technologically feasible to do so is a question that is overshadowed by the fact that its implementation would wreak economic disaster upon an industrialized country such as the U.S (Ember, 1975).

Thus, the only choice left is to implement standards quantitatively defining ''safe'' or ''unsafe'' levels of carcinogens in the environment. The actual establishment of such standards would be extremely difficult; however it seems to be the only socially and economically acceptable alternative.

Speculation on Human Carcinogenic Hazard

The emissions of organic compounds into the environment surrounding oil shale development sites have been quantified in terms of BaP emissions based on certain assumptions. These emissions of BaP were then followed through proposed flow mechanisms until a final probable concentration in a hypothetical human being living in the shale development area was determined. This level of concentration was calculated to lie between 0.1 and 10 ppm, varying by two orders of magnitude. Since no documented evidence as to just what the ''safe'' level of BaP might be in a human being was found in the literature, these calculated figures could not be related to a carcinogenic threat. Therefore, certain further assumptions were made in order to allow for a sort of wild speculation as to the extent of this threat.

The first assumption made was that the human carcinogenic potency of BaP, and therefore the shale site emissions, could be related to its mutagenic potency as determined by the Salmonella/microsome test. Undoubtedly, this is a far reaching assumption. First, as previously mentioned (Rubin, 1976), mutagenic potential and carcinogenic potential may not be definitely linked, and most probably not in direct proportion to each other. Further, BaP is not a proven human carcinogen; it has only been shown to exist in materials which are known to cause cancer in man (Clayson, 1962). Nonetheless, the assumption will be employed as it appears to be the only feasible method of making the analysis.

Table 2 shows that BaP is capable of inducing 121 revertants per nmole in the Salmonella/microsome test. If it is assumed that each nmole of BaP present in a human body is capable of causing a similar level of mutation and possibly cancer among cells in human tissues, calculations as to the number of cell alterations induced can be made. For instance, a level of BaP of 10.7 ppm in the human body would mean that 2970 μmoles, or 2,970,000 nmoles of BaP would be present. This amount of BaP might be capable of causing approximately 3,600,000 cells to mutate. Table 10 shows the number of cell mutations that might be

Table 10. Potential cell mutations induced by various levels of BaP in the human body.

BaP Concentration (ppm)	BaP Quantity nmoles	Number of Possible Cell Mutations
10.7	2,970,000	3,600,000
1.07	297,000	360,000
0.107	29,700	36,000

caused by the various levels of BaP in the human body taken from Table 9.

Whether or not these levels of mutations would induce cancerous tumors within the human body is unknown. However, 3.6 million cell mutations would seem to be a considerable cancer causing threat.

It must also be remembered that the BaP concentration was employed only as an indicator of carcinogenic potency. Thus, other factors may be present which would increase the carcinogenic risk. In addition the recent examples of vinyl chloride and asbestor exposure resulting in long term carcinogenesis serve as more than adequate warning to attempts for foresee environmental hazards (occupational and/or general population) associated with industrial development and activities (Ember, 1975; Hills, 1976).

CONCLUSIONS

One of the purposes of an environmental assessment is to foresee potential problems created by the introduction of contaminants into an ecosystem and to suggest appropriate control devices to mitigate the effects of such inputs. In the case of the oil shale industry, very little is known about the potential hazards, especially those related to the emission of organic compounds with carcinogenic potency. The hazards will probably be due to chronic exposures to the emitted compounds and the effects of such exposures are likely to take years to manifest themselves, as is the case with many carcinogenic substances. A precise evaluation of these hazards awaits commencement of operation of commercial scale oil shale processing facilities. However, it is hoped that this report will stimulate future research into the effects and control of discharges of carcinogenic materials from oil shale development sites and result in the anticipation of potential problems.

The conclusions drawn in this study are based on an oil shale development complex incorporating a TOSCO II retorting facility capable of producing 100,000 barrels of shale oil per day. Other assumptions were made as necessary and are indicated in the appropriate sections. An analysis of the major assumptions made is presented in the discussion section.

1. The assumptions and models employed in this study are the essential components underlying the figures calculated. The figures must be related to the assumptions in order to have significance. Therefore,

an understanding of the assumptions and models may be more important than the figures derived from them are.

* If this is true then why publish unfounded numbers that would cause concern among layman not familiar with the method of analysis

2. The predicted annual atmospheric emissions of particulate matter from both the retorting and disposal sites would contain 0.6 kg of BaP.

3. The predicted annual atmospheric emissions of gaseous hydrocarbons from the retorting facility would contain 75 kg of BaP.

4. The assumed annual vaporization of hydrocarbon compounds from the spent shale piles could introduce 175 kg of BaP into the atmosphere each year.

5. A total of 250.6 kg of BaP would fallout or washout of the atmosphere each year and would eventually flow into area surface waters.

6. The predicted annual production of spent shale would contain 3500 kg of BaP.

7. The assumed runoff and leachates from the spent shale piles could introduce 210 kg of BaP into area surface waters each year.

8. Area surface waters will act as the ultimate collecting point for all BaP emissions from the shale site once equilibrium is established.

9. The calculated maximum mean annual BaP concentration in the atmosphere surrounding the shale development site might be 5.7×10^{-4} $\mu g/m^3$.

10. The calculated average concentration of BaP in the waters of the White River, should the oil shale development take place in Utah, might reach 7.56×10^{-4} mg/l.

11. Aquatic producers living in the White River may contain BaP concentrations of 0.756 ppb.

12. Aquatic herbivores living in the White River may concentrate BaP up to 7.56 ppb in their tissues.

13. General carnivores living in the White River may concentrate BaP up to 75.6 ppb in their tissues.

14. Top carnivores living in the White River may concentrate BaP up to 756 ppb in their tissues.

15. Uptake of BaP originating in shale development site emissions by terrestrial producers would not be significant.

16. A cow grazing exclusively within a 5 mile radius of the shale development site may ingest enough BaP to reach a level of 620 ppb in its tissues.

17. A man living in the shale development area for 20 years could inhale 95 μg of BaP.

18. A man living in the shale development area for 20 years and drinking only water from the White River could consume 5.52 mg of BaP with his water.

19. A man living in the shale development area for 20 years and obtaining all of the fish he eats from the White River and all the beef he eats from cows grazing within a 5 mile radius of the development site could ingest 750 mg of BaP with his meat.

20. The food chain would act as the most important mechanism for the transfer of BaP from the environment to man. The quantity of BaP transferred through the food chain overshadows inhalation and water consumption combined.

21. The resultant concentration of BaP in a man spending 20 years of his life in the shale development area could reach 10.7 ppm.

RECOMMENDATIONS

1. The organic compounds present in the atmospheric emissions from the shale retorting and disposal sites need to be identified and quantified so that the actual flow of BaP, as well as other potentially carcinogenic materials, into the environment with these emissions can be evaluated.

2. The carcinogenic potency of the atmospheric emissions needs to be evaluated. This would involve testing the combined emissions, not the separate compounds, in order to assess their potential effects on organisms living in the area of atmospheric pollution.

3. The volatilization of hydrocarbon compounds present in the spent shale piles needs to be investigated. Calculations made in this study indicate that the volatilization of these compounds could be a major source of vaporized BaP in the atmosphere. Research is required to determine the actual extent of this volatilization so that its role in atmospheric pollution can be assessed.

4. The mechanisms by which the vaporized hydrocarbon compounds, especially the carcinogens, are removed from the atmosphere should be defined. This study assumed complete adsorption onto particulate matter. Research into the exact extent such adsorption will play in vapor removal, as well as the roles of other removal mechanisms needs to be carried out in order to more adequately define the flow patterns of these compounds.

5. The organic compounds present in leachates and runoff from the spent shale piles need to be identified and quantified so that potential

flows of BaP, as well as other carcinogens in these emissions can be evaluated.

6. An assessment of probable quantities of water which will escape from the confinement structures surrounding the shale pile into the environment should be made. The confinement facilities certainly will not be 100 percent effective and a realistic evaluation of the potential for waters to escape needs to be carried out.

7. Research into methods of containing the leachates and runoff from the spent shale piles over extended periods of time needs to be conducted. Presently, little concern has been given to this containment beyond the 20 year life of the shale processing facility.

8. The interactions of BaP, as well as other carcinogens within the aquatic ecosystem need to be assessed. Mechanisms of organism uptake need to be identified. Specific tissue retention of the compounds needs to be evaluated. Food chain linkages in the flow of BaP must be identified. The effects of various concentrations of the carcinogens at different trophic levels need to be assessed. All of this will allow for an overall evaluation of the hazards created in an aquatic ecosystem by the emission of organic carcinogens from the shale development sites.

9. In the same way the interactions of these compounds within the terrestrial ecosystem need to be assessed. Mechanisms of uptake and introduction into the food chain need to be identified. Specific sites of tissue retention of the compounds need to be determined. Food chain linkages must be defined. Effects of various concentrations of these

compounds on specific organisms need to be evaluated. All this, again, will allow for an overall assessment of the hazards created by these compounds in the terrestrial food chain to be made.

10. The grazing of terrestrial herbivores on or near the shale development sites should be restricted so that the introduction of carcinogenic compounds into the food chain brought about by such grazing would be minimized.

11. The effects of various concentrations of the organic compounds emitted from oil shale development sites on man need to be assessed. This assessment will then allow for the promulgation of either effluent or receiving body standards for the emission of these compounds into the environment.

12. Perhaps evaluation of similar fossil fuel processing facilities dependent on coal, oil, tar sands or other energy sources could be used to validate the approach used in the study.

General Comments

The use of non-quantifying adjectives such as tremendous, devastate (verb), etc. should not be used in a report that lacks site specific data.

A lot of the data submitted in this report is not applicable to the Utah tracts (p. 59 for example)

The objective of the report was to assess the theoretical human health hazard posed by carcinogenic organic compounds entering the environment from oil shale development. In my opinion the report does not meet this objective and should be used only to define areas of research needs.

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